NETWORK STRUCTURES AND RESOURCES FOR EMERGENCY COMMUNICATIONS

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Master of Philosophy

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SUMMARY

The aftermath of a major emergency is heavily dependent on communications. Existing communications networks may fail as a direct or indirect consequence of the emergency and these studies suggest that this leads to a requirement for temporary communications networks, usually within the emergency ground. Such networks are likely to have a high dependence on radio technology in order to maintain their portability. Major emergencies are unpredictable and èdynamicí in their resource requirements; consequently it is often not possible to develop permanent fixed networks that will cope with every form of major emergency.

Emergency services in the United Kingdom each have their own radio networks which are adequate for everyday operations; but during a major emergency there is seldom a capability for inter-working between these networks or the ability to construct temporary networks using resources shared by the services. The primary incompatibility lies with the radio equipment itself which varies between the various services, or even between different regional groups of the same service.

This thesis will identify reasons why existing communications networks may fail during a major emergency and hence justify the need to develop schemes for the implementation of temporary communications networks. It will also propose that a solution to the primary incompatibility of radio equipment might be solved by the development of radio equipment that is common throughout the emergency services but is programmable to the needs of the particular using service.

Major Incident
Emergency Planning
Disaster
Communications Failure
Temporary Networks

ACKNOWLEDGEMENTS

There is little in this world that is achieved is isolation without the help and support of others. Therefore I should like to thank Dr. Peter Best for supervising this project and Dr. R. Brewster, Dr. J. Penny, Prof. W. Toby Norris and Karen Shaw for helping me prepare this thesis.

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CHAPTER 1

INTRODUCTION

This thesis contains a description of the author's doctoral research which was a study of the special communications problems which arise at major incidents or disasters. A major aim of this study was to identify the facets of emergency communications which, due to the nature of major emergencies being unforeseen, set them apart from conventional, permanent communications infrastructures. However, established communications engineering methods and techniques can nevertheless continue to be used to good advantage.

During the decade of the 1980s there were some thirteen major incidents which had a direct bearing on the United Kingdom and at many of these incidents it was commented that there had been a failure of emergency communications. The central focus of this research work was an investigation into why fixed communications networks fail during a major emergency and how one might alleviate this problem, perhaps with the use of temporary resources.

These temporary resources need to be portable so that they may be installed at a moments notice to fulfil a communications need that has arisen due to any one of a variety of reasons. The need may be for inter-site communication, inter-service communication (in both the retained and voluntary services sectors) or even inter-country. There may be a need to set up a network at short notice in an area where none currently exists, such as third world areas, in response to some long or short term disaster.

These investigations were split into suitable individual modules to allow rigorous investigation of the topic to take place, each of these modules shall now be described in turn below.

1.1 The CAIRO Scheme

The starting point for much of this work was the authors direct experience in training to handle communications traffic at the scene of a major emergency as a member of RAYNET, The Radio Amateurs Emergency Network. RAYNET is a UK wide voluntary organisation comprised mainly of radio amateurs who make their services and equipment available in times of disaster to provide additional communications facilities.

Members of RAYNET have developed the CAIRO scheme which is now accepted as a de facto standard throughout all members of RAYNET for remote operations from a radio transceiver. The scheme takes the essential signals required for operating a two way radio transceiver on a single radio frequency and presents them in a standard format so that one may operate the transceiver with a variety of passive audio accessories either adjacently or at a remote location.

Part of the philosophy behind the scheme is that the establishment of a radio station by a RAYNET member can be rapid regardless of the actual operators and equipment involved, various items of personal equipment complying to the standard will be compatible with each other allowing a simple 'plug and go' method of establishing a communications network. This philosophy has been extended throughout this work.

Another aspect of the CAIRO scheme that has been investigated in these studies is the use of active accessories connected to CAIRO compatible radio transceivers to extend network provisions and functionality.

1.2 Emergency Communications Network Failure

It has already been pointed out that in response to a major emergency the communications networks of the emergency services are liable to failure, a fact that has been highlighted in many of the major incidents that occurred during the decade of the 1980s.

This work studied many of these major emergencies and others of varying size from around the world and attempted to identify the reasons why the communications networks had failed in each of these cases. The aim of this rigorous investigation was an attempt to see if there were any common factors in the failure of these networks or if the situation was unique in every case. It was hoped that one would find some causes of network failure as it is often difficult to attempt to solve a generic problem without a common cause or causes of the problem.

It is believed that this work has not been undertaken before and many users of emergency services networks do not understand the reasons why their networks might fail, they simply accept that it is 'par for the course' when a major incident occurs.

This investigation did in fact yield five common factors as to why an emergency communications network might fail and it is hoped that this can be used to develop solutions.

It is worth mentioning that this investigation also considered how the emerging technologies that are being planned for emergency communications use might cope in the same conditions.

1.3 Solutions To Communications Network Failure

The next stage of this work was to see if there currently existed a means by which one could prevent or recover from the failure of an emergency communications network. This involved a study of the communications systems that are already in use by the emergency services and the particular facilities that each of them offer to see how they cope with network failures. In order to provide coherency to the argument this study was conducted with respect to the five failure modes that were previously identified within this work.

The aim of the above study was to see how one might try to build emergency communications networks, using a combination of the current systems and technologies, that might be capable of coping with all types of major emergency and consequently not fail when responding to them. Various methods of constructing these networks were considered using examples of current systems that are in use. How these proposed systems might cope with a major incident was theorised with respect to the five failure criteria.

Within this section it is suggested that the best method of coping with the quantity and urgency of traffic that occurs after a major emergency might well be in the use of temporary resources and communications networks. This was suggested as an alternative to trying to build networks that do not fail; as major emergencies, by their very nature, are unpredictable and their requirements difficult to gauge in advance. It was suggested how a temporary network might be used to solve each of the five failure criteria.

Finally this section referred back to the examples of network failure that were cited in the previous sections and suggested how temporary emergency communications networks might well have been used in these cases to relieve the problem identified, thus forming a link with the problem identified and the solution suggested.

1.4 A Study of Temporary Communications Network

Having suggested that a viable solution to emergency communications network failure might well be in the use of temporary communications networks this section of the work takes a closer look at the types of temporary networks that could be set up.

This section suggests various different topologies that might be used and when one might decide to use them. Here, again, reference is made to the five failure criteria and how each of the suggested topologies might address these problems.

Initially the study is based upon current communications technology that is currently available, with some of the topologies being simple and quick to implement requiring the minimum amount of apparatus, and others being more complex offering a versatile communications system that might take longer to install. The more complicated solutions might well be used in the secondary phase of a major incident that becomes protracted and requires more flexibility.

This study will then take a short look at how temporary communications networks might well be constructed from the new technology communications systems that are currently emerging and are intended to replace the existing networks used by the emergency services. The ideas developed here need to be upward compatible with the new systems otherwise they will only have a very limited life.

1.5 Engineering Facilities for Temporary Communications Networks

In addition to considering the developments and operation of emergency communications networks as a whole, both fixed and temporary, these studies have spent some time investigating the physical engineering aspects of certain parts of radio communications systems. This has included the undertaking of a fair degree of practical work in the earlier stages of this work.

Two projects in particular merit discussion in this presentation, these being the construction of the control mechanism for an independent radio relay system and the development of a specification for the 'ideal' emergency services radio transceiver.

A radio relay system or repeater consists of a coupled transmitter and receiver where the transmitter re-radiates signals received so as to primarily increase range between mobile radio transceivers and from fixed points to mobile transceivers. Such a device might be a fixed permanent network resource or installed temporarily in order to help construct a temporary communications network. To operate independently the repeater obviously needs some form of control system in the cross coupling between the transmitter and receiver. It is the development of a suitable control system that has been the focus of this section of the work; one that might be varied in its operational parameters in response to the users' requirements. Such a system was built and is currently operational.

Some time was spent considering the requirements of an ideal emergency services radio transceiver that would offer all the requirements for routine and emergency operation, such a device has been dubbed the 'smart' transceiver by this work. The aim of this was to do away with the primary incompatibility that exists in emergency services radio systems, that of the radio transceivers itself. To provide a radio transceiver that is configured for routine operations and yet be re programmable to operate with different networks, fixed or temporary, in response to a major emergency.

1.6 Further Work

Finally, it is accepted that this is a topic that will never be fully solved or closed. Although the emergency services in the UK are still using the same design of communications networks that they were using during the 13 major incidents in the 1980s a lot has occurred in the development of new systems that will hopefully start to be commissioned in the early part of the next century, if not the end of this.

This section suggests how this work might be applied to the new emerging networks and how these networks should be investigated to see how they might perform with respect to the five failure criteria identified here.

With the new networks there tends to be a shift towards using systems operated by commercial network providers, even if the network remains private to the emergency services. There is also the emergence of the public verses private network debate, some arguing that public networks might in fact offer a better grade of service. This section suggests how one might investigate this debate and study some emerging public networks for emergency services use, perhaps only during a major emergency.

CHAPTER 2

THE CAIRO SCHEME

CAIRO is the Communications Audio Interface for Remote Operations and is a scheme by which the essential signals to operate a voice radio transceiver are presented in a standard format. CAIRO was developed by members of RAYNET, The Radio Amateurs' Emergency Network, to allow the quick establishment of temporary radio stations.

It is the principles behind the CAIRO scheme that were some of the starting points for this research work and, although the scheme in it's current form was largely complete prior to this work commencing, certain aspects have been considered in these studies. Consequently the scheme and the subsequent work associated with it are presented here.

2.1 RAYNET

RAYNET is The Radio Amateurs' Emergency Network and is a UK wide voluntary organisation consisting of radio amateurs who make themselves and their equipment available during times of emergency for the establishment of temporary communications networks using amateur radio frequencies [1]. RAYNET provides its user services with temporary emergency radio communication which may either replace or complement a radio network that is already in place. The user services are clearly defined in the amateur radio licence as...

County Emergency Planning Officers (CEPO),

Any United Kingdom Police Force, Fire or Ambulance Service

British Red Cross Society,

Saint Andrew's Ambulance Brigade,

Saint John's Ambulance Brigade,

Her Majesty's Coastguard,

Health Authorities

Government Departments

Public Utilities (Gas, Electricity, Water Companies, etc.),

and Any other group nominated by the responsible CEPO.

RAYNET may be called by any of these user services and is permitted to use amateur radio frequencies to pass emergency traffic on behalf of the calling user service. The organisation is now sufficiently established within the UK that it now regularly appears within the major incident plans of many of the above user services, both retained and voluntary [2 & 3]. As RAYNET is a voluntary organisation that is self funding, the vast majority of the radio equipment used for RAYNET operation is the personal property of the radio operator.

Although RAYNET is a voluntary organisation it is now much respected in the United Kingdom as having the ability to provide a professional service, in much the same way as other voluntary organisations provide quality facilities such as mountain rescue or lifeboat services. There is now a wide acceptance within the retained emergency services of the ability of voluntary organisations to provide valuable assistance at the scene of an emergency [4, 5 & 6].

The nature of the role that RAYNET will have at a major emergency dictate that it is necessary to set up temporary radio communications networks swiftly, it was this requirement that lead to the development of the CAIRO scheme.

2.2 The CAIRO Scheme

The CAIRO Scheme was developed by members of RAYNET to enable them to operate efficiently when handling emergency communications. The preliminary work started in 1983 with the adoption of the acronym CAIRO taking place in 1987.

RAYNET members mainly use their own radio equipment for two way radio communication usually on narrow band FM channels. Given that the equipment is made by a variety of manufacturers there is rarely compatibility between the audio accessories for each of the radio transceivers, items such as microphones, loudspeakers, headsets, etc. CAIRO addresses this problem by presenting the audio signals of a voice radio transceiver in a standard format to allow any compatible audio accessory to be used with any compatible radio transceiver.

2.2.1 The CAIRO Signals

The CAIRO scheme has been developed to carry the three signals that are considered to be the three essential signals that require accessing once a voice radio transceiver has been set up for operation on a particular single radio channel (be it simplex operation or part of a more complicated trunked or routed network). The three signals are...

1) The speaker circuit or received audio output,
2) The microphone circuit or transmitted audio input,
3) The push to talk (PTT) or enable transmission circuit.

These signals are combined on the first five pins of the now familiar 7 pin DIN connector. The remaining two pins have signals assigned to them but these are considered to be optional signals within the CAIRO scheme. Figure 2.1 shows the CAIRO signal to DIN pin assignment.

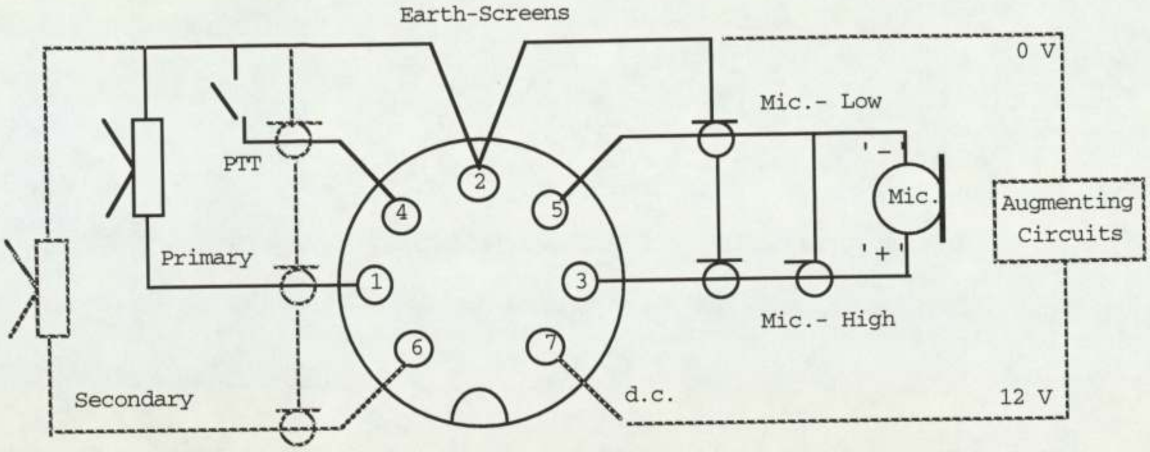

Figure 2.1 - The CAIRO Signal to DIN Pin Assignment

Pin 2 is defined as the 0V connection or system ground to which most signals are referenced.

The primary audio output (pin 1) is defined to be at loudspeaker level direct from the radio transceiver and is referenced to 0V. This signal is readily available and capable of driving loudspeakers and headphones alike, it's level can be adjusted by the front panel volume control to set a level suitable to overcome any line losses should a long CAIRO line be used.

The PTT signal is used to place the radio transceiver into transmit to broadcast the transmitted audio signal. It is defined that the radio is placed into transmit when a metallic contact is placed between pins 4 and 2, the PTT and 0V. The metallic contact may be generated by a switch or relay but the CAIRO specification clearly states that it should be metallic so that no fixed voltage drop associated with semiconductor switching is encountered.

It can be seen from figure 2.1 that the microphone circuit has two independent conductors. As the microphone is the lowest level signal carried by the CAIRO scheme it is the most vulnerable to interference as it operates at normal microphone levels, especially if a long signals line is used. The only current flowing in the microphone conductors is that due to the microphone itself meaning the currents in each conductor are equal and opposite achieving a balanced line and better noise immunity. It is highly likely that one of the microphone conductors is referred to 0V at the radio transceiver (usually mic low, pin 5) but it should be isolated from 0V at all other points.

CAIRO also specifies that a small, current limited, DC bias be placed across the microphone pins so that both electret and dynamic microphone capsules might be used.

Pin 6 is an optionally wired secondary audio pin and usually carries the same signal as pin 1, the received audio. The two pins are used to separately carry the received audio to each side of a binaural headset so that the signal level in each ear may be separately controlled if desired.

Pin 7 is an optionally wired pin that may be used to carry a DC supply voltage between 9V and 14V, referenced to 0V.

To convert a radio transceiver to the CAIRO standard it is recommended that one builds an external adapter which mates with the specific connectors on the radio and then presents them on a seven pin DIN socket in the format described above. Often this adapter is a passive item merely re-presenting the signals on a different connector. Sometimes a few additional components are required if the radio does not present the essential signals in the format required; an example of this would be making provision for the DC microphone bias if not already present.

Any accessory wired to the CAIRO standard will now work with any CAIRO adapted radio transceiver an may fulfil one or more of the three essential functions; speaker, microphone or PTT. The three functions are covered by a combination of one or more suitably wired accessories connected to parallel wired sockets. It can be seen that in the vast majority of cases CAIRO accessories will contain only passive items and in the simplest case are constructed from transducers (speaker or microphone) and switches.

The scheme specification is fully documented in The CAIRO Manual [7].

2.2.2 The Advantages of CAIRO

Having all available radio transceivers and audio accessories converted to the CAIRO standard has definite operational advantages which have enabled RAYNET to quickly set up and maintain temporary communications networks, these benefits shall be briefly discussed.

No two radio operators or operations rooms are the same. As a result different forms of operating accessories may suit different circumstances. For example, in a control room one radio operator may prefer a telephone type handset with an integral push switch for the PTT (this is a complete accessory containing all three functions in a single housing), whereas another radio operator may prefer to use a headset complete with boom microphone in conjunction with a foot switch for the PTT signal. If one has a range of accessories wired to the CAIRO scheme they will work with any CAIRO adapted radio transceiver on a 'plug and work' basis.

The CAIRO scheme was specifically designed to allow the three essential signals to be extended, via a suitable cable, some distance from the radio transceiver, up to 200m can physically separate the radio transceiver and operating position, so called remote operations. This remote wiring has many advantages including the efficient layout of station equipment (put the radio in the corner out of the way) and the rapid installation of a station at a temporary site.

Should any CAIRO converted radio transceiver or accessory fail during operational use then the part may be rapidly exchanged for another, what has been dubbed 'swift repair by substitution.' A facility that is most desirable when handling emergency traffic and not so practical if each radio transceiver has its own specific audio accessories.

2.2.3 Validation of the CAIRO Scheme

The CAIRO scheme has now been used by RAYNET members in many operational situations which have given full validation of it's principles. One of the largest RAYNET responses ever was in response to the Lockerbie incident in December 1988 when the CAIRO scheme was used by both operators 'in the field' and those in the control centre for efficiently setting up a temporary control centre.

The report on the telephone exchange fire at Corbett Hospital [8] makes specific reference to how the CAIRO scheme enabled an efficient response.

In 1992 the author joined a team of RAYNET volunteers in Romania who provided communications between local relief projects and the UK. The CAIRO scheme was used to establish many of the temporary radio stations to great effect.

2.3 CAIRO-8

Since its development the CAIRO scheme has become most popular and has indeed helped RAYNET operators to achieve all the advantages discussed above. However, it was discovered that the CAIRO scheme also had shortcomings when it came to the interfacing of active accessories to a transceiver and thus the requirement for an enhanced CAIRO was born, the scheme was called CAIRO-8.

CAIRO-8 was developed by the author just prior to the commencement of these studies and is fully documented in The CAIRO Manual [7]. In the early stages of these studies further development and validation of the CAIRO-8 standard was undertaken, for both the standard itself and the range of accessories it could now support.

To present the CAIRO-8 scheme it is first necessary to examine the deficiencies of the CAIRO scheme.

2.3.1 The Deficiencies of CAIRO

All of the above advantages of the CAIRO scheme have been described with respect to the use of passive accessories. If CAIRO is to be the standard connection scheme for the audio signals interface on radio transceivers used by RAYNET, then any active module that interfaces to the audio signals of a radio transceiver should do so through the CAIRO scheme. Typical examples of active modules used by RAYNET are talkthrough units, to form temporary radio relay stations, and radio modems for data transfer.

The deficiencies in the CAIRO scheme come to light when one uses it as a connection scheme for connecting active modules to radio transceivers. In order to identify these deficiencies it is advantageous to first investigate the transmit signals associated with the CAIRO scheme.

Most microphone elements used in radio communications schemes tend to have similar sound pressure sensitivities meaning that most radio transceivers have similar, if not the same, microphone input sensitivities. This can be interpreted as a common fixed audio input level. The CAIRO scheme also has a push to talk (PTT) or transmit line which is used to unequivocally place that radio into transmit for the passing of information.

It has been identified that the transmit connections in the CAIRO scheme offer the user with a fixed input signal level with an associated DC signalling line to indicate that the input is being used, a fairly rigorous definition. However, when one investigates the receive signals associated with the CAIRO scheme the definition is by no means as rigorous. The only receive signal available is the loudspeaker output line from the radio which is not at a fixed level as it depends upon the volume setting on the front panel of the transceiver. There is no DC signalling line to indicate whether the speaker line is active or dormant, even though circuitry within the receiver might well mute received noise when there is no radio signal present at the input.

In order to achieve full interconnection between radio transceivers and active accessories one should have a fixed level audio output with associated DC signalling line to indicate that it is active, and a fixed level audio input with associated DC signalling line to indicate that it is active. The CAIRO scheme only offers the latter two of these four signals.

2.3.2 The CAIRO-8 Scheme

The case for enhancing the CAIRO scheme with the inclusion of two additional signals, namely a fixed level received audio output and associated DC signal, was stated above. In order to carry these two additional signals and cause no conflict with the original specification of the CAIRO scheme it was decided to move to an 8 pin DIN connector for the enhanced version of CAIRO; hence the name CAIRO-8. The signal to DIN pin assignment of CAIRO-8 is given in figure 2.2

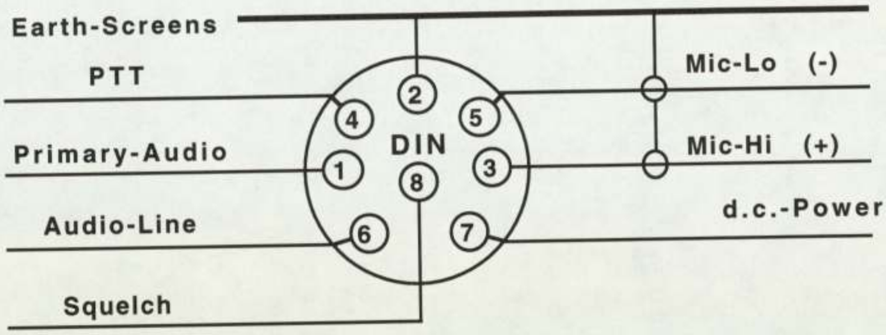

Figure 2.2 - CAIRO-8 Signal to DIN Pin Assignment

As can be seen from the above diagram the geometry of the first seven pins of the eight pin DIN socket is precisely the same as that of the seven pin DIN socket. CAIRO-8 makes use of the DIN mating hierarchy and presents the three essential signals (microphone, speaker and PTT) on the first five pins of the socket in the same way as CAIRO does. This means that any accessory that is CAIRO compatible is also CAIRO-8 compatible, in short CAIRO-8 offers all the advantages of CAIRO and more.

Further investigation yields that CAIRO-8 is 'self policing.' An active accessory that requires the additional signals of CAIRO-8 will be furnished with an 8 pin plug; due to the presence of the centre pin it will not physically mate with a 7 pin DIN socket found on a CAIRO only radio transceiver. Any CAIRO accessories will of course mate with a CAIRO-8 transceiver.

The two forms of CAIRO have been developed to operate side by side as opposed to CAIRO-8 replacing CAIRO. In the vast majority of cases the signals required to convert a transceiver to CAIRO-8 are not all available externally, meaning the conversion to CAIRO-8 is an internal modification which might invalidate an existing warranty. The fact that a radio can be converted to CAIRO my means of an external adapter warranty agreements are not invalidated. It is declared that the presence of an 8 pin DIN socket on a radio transceiver for its audio interface is an indication that it has been converted to CAIRO-8.

2.3.3 The Additional Signals of CAIRO-8

There are actually three additional connections in the CAIRO-8 scheme, these being the two signals identified as 'missing' previously and a power connection.

In CAIRO-8 pin 6 is defined to carry the fixed level audio output from the radio transceiver. This is declared to be the same as the audio signal that appears on the loudspeaker output of the radio (primary audio, pin 1) but fixed in level. As described previously, it is usual for the speaker output to be muted when the radio is not actually receiving a signal so that the operator is not irritated by noise, this being controlled by the squelch circuit. It is declared that this signal is controlled in the same way so that it is essentially the same as the signal on pin 1 except that it is fixed in level. The audio line output is defined to be 1 volt peak with an output resistance less than 600Ω and referenced to 0V, pin 2. This level was chosen as it is close to the professional 0dBm signal level into 600Ω but is defined by voltage as it is intended to be a voltage driven system for one or more high impedance loads.

The squelch signal is a DC signal that indicates whether the audio line is muted or active and is derived from the transceivers receiver squelch circuit. The squelch output is defined to be a pair of metallic contacts 'behind' the CAIRO-8 socket. Essentially the contacts are those of a reed relay which are driven by the internal squelch circuit and are good for carrying up to 0.5A. The definition states that these contacts shall be closed between pin 8 and pin 2 with the presence of a signal that opens the receiver's squelch presenting a path to 0V. When the radio is not receiving a signal the contacts are open. This definition is the complement of that for the PTT signal in both forms of CAIRO.

Pin 7 is an optional power connection within the CAIRO scheme and has no precisely defined level. Within CAIRO-8 power is defined as always being present when the host transceiver is switched on. CAIRO-8 is an enhanced version of CAIRO specifically for use with active modules so that a fixed power supply within the scheme was deemed necessary. This voltage is defined as 13.8V ±15% referenced to 0V and is to be good for supplying 1A. This is the same specification as the supply voltage for many radio transceivers and hence is easy to derive.

A more detailed description of how these signals are derived is given in other publications [7 & 9].

2.3.4 The CAIRO-8 Bus Structure

The above three signals defined in CAIRO-8 have created a bus structure for the chaining of active modules, the block diagram of a typical active module is given in figure 2.3.

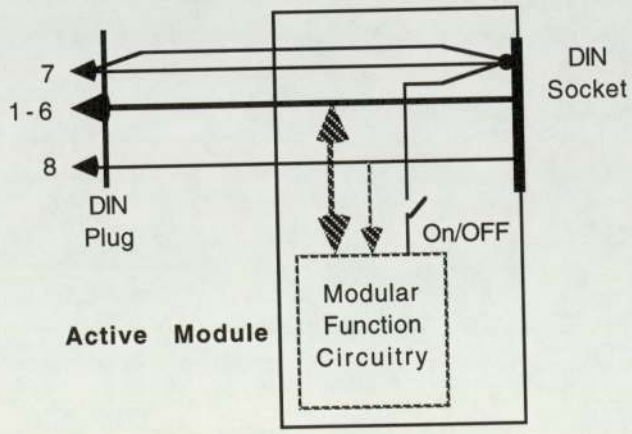

Figure 2.3 - A Typical CAIRO-8 Active Module

It is recommended that no more than five active modules be chained upon the bus and less if the power supply limit of 1A would be exceeded. CAIRO-8 is not designed for long line transmission (unlike CAIRO) so it is recommended that modules remain within close proximity (say 2m) of the host radio transceiver. The main limiting factor here is the voltage drop that would be experienced on the power line given the size of cable that can be sensibly used. There is no reason why, at the end of the chain of active modules, one could not extend the conventional CAIRO signals to facilitate remote operations of the three essential signals (microphone, speaker and PTT).

Now that the bus structure of CAIRO-8 has been defined it is possible to develop a whole range of active and passive accessories to enhance the swift construction of temporary radio networks for emergency communications.

2.3.5 The Adoption of CAIRO-8

In the early stages of these studies validation of the CAIRO-8 scheme was undertaken which included the conversion of many radio transceivers to the standard and the development of some active accessories. During this work negotiations took place with a UK manufacturer of amateur radio transceivers, the result of which was that it is now possible to buy transceivers already conforming to the CAIRO-8 standard.

2.4 Combining Voice and Data with CAIRO

Within existing Private Mobile Radio schemes there are accepted methods by which voice and data can be combined on a single radio network [10, 11 & 12], but such schemes tend to require specially converted radio transceivers. Within RAYNET it was perceived that there is sometimes a need to build such mixed mode networks with the same 'plug and go' ease that the CAIRO scheme offers to voice radio networks. CAIRO-8 does offer an answer [13].

Using the PTT and squelch signal lines with an appropriately converted AX25 radio modem conforming to CAIRO-8 (an active accessory); such a modem and voice accessories can be plugged into the same or different CAIRO-8 transceiver to operate on a single radio network. The result is a combined voice and data network where voice transmissions take priority over data transmissions. This is achieved by the radio modem monitoring both the squelch and own local PTT lines to check if the radio channel is in use by voice traffic being received or locally transmitted; the modem will only transmit data if both yield a negative result. The result is that the voice users do hear the data transfers too, and it is suggested that such a network is suitable for low data rates and high voice traffic. High data rate radio systems should really be on independent networks so as to achieve the required throughput.

2.5 Other CAIRO Accessories Considered

Within the scope of this work some development of CAIRO accessories has taken place, these shall be briefly described below.

2.5.1 Improved Dual Op Box

The Dual Operator Box is a CAIRO accessory that allows two operators to be connected to one transceiver. Both operators have access to the received audio but only one operator has control of the microphone and PTT signal, the active operator. The active operator is chosen by means of a switch on the Dual Operator Box.

When attempting to construct a Dual Operator Box the author found that the internal wiring quickly became very untidy and rather difficult work with. This is something that, in the past, has been tolerated by constructors of the Dual Operator Box in order to gain the operational efficiency that it offers. However, the author felt that a better method of construction could be found that would also aid maintenance and repair should it ever be necessary, this being another principle of the CAIRO scheme.

An improved method of construction was devised and evaluated and was found to be most satisfactory. A prototype of the improved Dual Operator Box was used by the amateur radio operators in Rumania and found to be operationally no different from the original design. This was exactly what the author had desired in developing the new version. Full constructional details are documented [7 & 46].

2.5.2 Repeater Logic

A radio relay station or repeater is an unmanned slave station consisting of a receiver coupled to a transmitter, and uses an in-built control system usually called the 'logic'. The intention of a repeater is to increase the available communication range between radio users that are usually mobile or between a fixed and mobile station. This logic controls the operation of the repeater, allowing only signals to be relayed that are of intelligible quality, transmitting the repeater's identification, and usually limiting the talkthrough time to a predetermined time limit. It would be a waste of power and lead to decreased reliability if the repeater were left in permanent transmit, so the logic arranges that the repeater's transmitter is only switched on when a valid input signal appears at the receiver for re-transmission.

In these studies the development of repeater logic as a CAIRO-8 active accessory was given some considerable thought; this work is documented more thoroughly later in this thesis.

The above presentation has shown how The CAIRO scheme was developed to enable RAYNET members to quickly and efficiently set up temporary radio networks to handle emergency communications. It has now been accepted by members of RAYNET nationally within the UK as the standard audio interface for radio transceivers.

In addition to the scheme itself there are many good underlying philosophies behind it, it is these philosophies that have had a bearing on the manner in which these studies were conducted.

CHAPTER 3

WHY COMMUNICATIONS NETWORKS FAIL

The emergency services currently have very extensive communications networks to assist them with their daily routine work and during times of large scale emergency. Most of these networks focus upon radio communication systems in order to maintain communication with mobile units, either vehicle or pedestrian based. The hub of these radio systems are the base station radio sites which are usually located in a favourable radio location (such as the top of a hill or tall building) and linked to the controlling centre (for example a police station) via a rented landline. These networks are very much fixed in their topology and have no capacity for dynamic expansion or variation in response to their users' needs. However, in response to 'ordinary' emergencies, the emergency services operate largely within their district of responsibility.

The users of these emergency services networks expect full availability of their communications networks for their everyday use, and expect that their networks will cope with large scale emergencies with no degradation of service. However, communications networks that rely upon fixed installations often do not cope with the quantity and urgency of traffic that occurs in the aftermath of a major emergency. There appears to have been little work into studying the reasons why emergency communications networks fail. This work takes as it's starting point a study of emergency communication network failure and tries to identify common causes which are now believed to fit broadly into one or more of the five following categories.

1) The cause of the emergency may have 'destroyed' key network resources.

2) The effect of the emergency may have contaminated strategic communication centres.

3) The volume of traffic may simply exceed the existing network capacity.

4) The existing networks may not adequately penetrate the emergency ground.

5) The existing networks may not have the inter-connectivity between them that is desired.

Many of these network failure problems have been encountered and commented on by emergency service personnel who have been involved in major emergencies. However, the reasons for the network failure have often not been understood, with few solutions to the problems being proposed. There now follows a more rigorous investigation of these failure modes using examples taken from real incidents.

3.1 Loss of Network Resource

Existing networks are obviously fixed in their nature using network resources at fixed locations. These resources might well be a radio base station located at a hill top site, the landline linking the base station to the controlling centre or the controlling centre itself. In the public networks the entire system is wholly dependant on fixed resources such as cellular base stations, even for mobile to mobile calls. If any one of these resources is lost then the communications network can be said to be inoperative or to have failed. It is quite possible that the incident itself creating a major emergency has caused one of these resources to be inoperative.

On 28th December 1989 an Earthquake struck the city of Newcastle in New South Wales, South Eastern Australia [6]. The State Disaster Plan was activated within 15 minutes but response was slow due to a loss of facilities, one of which was communications. The police headquarters suffered a power failure which effected communications plus there was damage to other sites housing radio base stations and other links associated with the local emergency communications networks. An example here of how more than one network resource was damaged by the emergency, rendering a network almost completely unusable.

In 1992 an Israeli cargo aeroplane ascending from Skippol Airport, Amsterdam crashed into a nearby accommodation tower block [14] causing many civilian casualties and fatalities, thus creating a major incident for all three of the retained emergency services to handle. In The Netherlands (as with many other western countries) it is custom and practice for the police to co-ordinate the emergency services' response, thus enabling the fire and ambulance services to undertake their specialist tasks with little hindrance. This includes the provision of co-ordinating emergency communications.

In this particular incident the base station radio for the local police forces was housed at the top of the tower block into which the plane collided rendering it inoperative. As the base station also acted as a relay unit for mobile to mobile communication this mode became inoperative too. For some considerable time after the initial impact the police forces were without any radio communication due to an inability for their radios to operate in a direct 'back to back' mode. This in turn placed an additional strain on the communications networks of the other two services. An Example of how the loss of a single resource caused an emergency communications network failure, again rendering it almost completely unusable.

3.2 Strategic Centre Contamination

Although the contamination and hence loss of a strategic control centre might considered to be a special case of the above scenario it is believed that aspects of this failure set it apart as a separate failure mode.

Most emergency communications networks are operated and controlled from a command and control centre where senior staff will control the emergency services response to a major incident. It is possible that the emergency itself might render this command and control centre inoperative or necessitate its evacuation; such as a flood or chemical leak. A failure of emergency communications might well occur in this case although the network itself might still technically be fully operative. It is this type of failure which sets this mode apart from the loss of a technical network resource.

In April and May of 1990 large floods covered more than 1 million square kilometres of Eastern Australia in Queensland, New South Wales and Victoria [3.1]; an area as large as France. In this instance many communities became isolated both physically and in terms of communications. The emergency services had to enact a disaster response but they were hampered by the fact that their own command and control centres were flooded making administration difficult and meaning that they did not have access to there own emergency communications networks whether they were working or not. An example of a contamination of a strategic centre.

3.3 Exceeding Network Capacity

When responding to a major emergency the emergency services usually make use of the existing networks that are used for routine operations, be them their own dedicated private networks or public communications networks that might routinely be used. The emergency itself might well create a volume of traffic that is in excess of that which the existing networks are capable of handling. This excess will cause a failure of the communications network. In the best case it will simply mean that messages are either delayed in being passed through the system or only a proportion of available messages are actually transmitted. In the worst case the communications network itself may well fail to operate at all as a result of the pressure placed upon it from the increased traffic volumes.

A classic example of the traffic exceeding network capacity is the Hillsborough Football Stadium Incident that occurred in Sheffield in April 1989 [15] when a large number of people were crushed within the stadium. The network that was initially overloaded was the police personal radio network. Too many officers were trying to pass information to control as to what was happening within the stadium, the result was that none of the messages got through due to the radio channel in use being blocked by simultaneous signals. This in turn delayed the emergency services' response to the incident and the implementation of the major incident plan.

As news relating to what had occurred very quickly filtered to the public domain (live in fact due to televised coverage of the FA Cup Semi-Final that was to have taken place), concerned friends and relatives started to telephone the hospitals and police stations around Sheffield from outside the city to enquire of people who were supposed to be in the stadium. This in turn lead to the switchboards of local hospitals and South Yorkshire Police being overloaded by calls of enquiry resulting in the local telephone exchanges being blocked. This caused the obvious frustration of people trying to get information but more importantly further hampered the major incident plan and virtually stopped all communication between the dealing hospitals and the emergency services. This example shows how both a public and private network simultaneously failed causing a major loss of emergency communication due to an overload from available traffic.

The Piper Alpha Oil Rig Fire of July 1988 [16 & 17] is an example of how a communications network offered a graceful degradation of service when the traffic being offered exceeded the network capacity. An oil rig, rescue helicopter or sea going vessel usually have no direct contact to any of the fixed public networks; all the communications traffic to handle this incident was dealt with almost exclusively on open voice radio channels that all parties had free access to. This did certainly help the operation in the respect that messages could be sent to the relevant party usually directly. The systems used were the VHF FM marine band and the HF SSB search & rescue and marine bands. Given that only a limited number of communication channels were available some traffic was caused to wait longer than was preferable before it was transferred to its destination. Given that these communications systems do not rely upon a network infrastructure and are technologically simple in their operation an overloading of traffic did not cause a total failure or blockage, traffic transmission time was simply lengthened.

It is worth noting that when open voice radio channels are subjected to these levels of traffic strict adherence to approved, efficient voice procedures is mandatory if the system is going to operate effectively. This was the case in this incident and it can be argued that the human operators are manually performing the tasks of scheduling and routing that a more complicated network would undertake automatically. This example showed that radio operators found this extremely tiring over a long duration and maybe one should consider that they, as message handlers, are part of the network and exhibited signs of failure under an increased traffic load.

An example of the failure of a public communications network when a major incident occurs is the setting up of a police casualty bureau [18]. A large incident involving a large number of casualties requires the collation of information as regard to those uninjured, injured and deceased, and matching this information with the telephone calls of concerned relatives and friends responding to media coverage. This task is the responsibility of the police and comes under the overall umbrella of a casualty bureau. If the setting up of telephone enquiry lines is not carefully managed then telephone exchanges local to the casualty bureau will become overloaded with calls and offer a poor grade of service to other local exchange users. This may in turn degrade the communications of the emergency services response if the bureau is set up adjacent to the incident itself. The service offered to those trying to contact the bureau might well be poor too if this scenario occurs, in the case of The Hillsborough Incident only 1000 of the attempted 1.75 million calls were answered [15].

Routine emergency services communications tend to take place over two way radio channels in either the VHF or UHF part of the radio spectrum. In order to cover large areas from a single control centre and operator, separate radio channels can be used to carry the same traffic, although the base station radios will be located at different locations; this sometimes being considered to be preferable to quasi synchronous operation on a single channel from multiple sites. In more recent years such systems have been improved so that the mobile radios employ a 'search, vote and lock' scheme choosing to operate through the base station offering the best signal level [19]. The problem with such networks during a major incident is that the traffic levels through each base station are likely to increase appreciably causing an overload for the single operator at the control point although any one single radio base station may not be in an overload condition based upon the level of traffic offered to it.

3.4 No Coverage Areas

When a major incident or accident occurs there is usually a large volume of communications traffic created within the area local to the incident, this is called the emergency ground. It may well be the case that existing emergency communications networks might not cover the emergency ground meaning that there has been an emergency communications network failure from the outset. It is highly likely that areas that are not covered by private networks belonging to the emergency services have very little or no public network access provision for mobile communications. What little service that there is available is likely to become very quickly overloaded creating a scenario described in section 3.3 above.

A classical example of lack of network coverage occurred in the Lockerbie Incident of December 1988 when a Trans Atlantic 747 jet aeroplane crashed on the Scottish Border Town having been the target of a terrorist bomb. The town itself was quite well provisioned for mobile radio networks used by the emergency services and had a reasonable level of public access cellular radio coverage for that period too. These networks were quickly overloaded with the volume of traffic offered but more importantly the main communications failure was that many of the outlying rural areas that had to be searched for wreckage had no network coverage at all causing the rescue and investigation teams major difficulties. In this instance temporary mobile radio networks were provided by RAYNET.

The mass stranding of Whales at Strahan on the Eastern Coast of Tasmania in October 1992 [20] provides a different example of how a lack of network coverage can hinder a major incident. No one understands what causes a mass whale stranding and why they occur at the locations they do but in this case 76 whales beached in a remote area where there is little network coverage due to the small civilian population in the area. this incident caused a large influx of people and the requirement to implement a major incident plan. After initial assessment and stabilisation of those whales still alive the use of a heavy duty forestry commission tractor was required. Due to no communications network coverage in the area an unforeseen breakdown in communication occurred and the tractor arrived some two hours later than was initially planned for. This caused the loss of some more whales that might have otherwise been saved.

Some emergency services communications networks also incorporate an Automatic Vehicle Location (AVL) scheme that interfaces with a Geographic Information System (GIS) at the control location. Such systems make routine operations much simpler as the control operators can see the location of all their units instantly on a continuously updated screen. These schemes usually operate by coupling a Global Positioning System (GPS) receiver to the vehicles mobile transceiver [21] so that position data is regularly transmitted to the control location through the network, the hardware being replicated in each vehicle. If an incident occurs in an area with no network coverage not only will the personnel in the mobile unit loose communication with their control point but the vehicle's location will be inaccurate at the control location and an alarm may well be triggered by the GIS as the vehicle is no longer within communications contact. This situation will only make the control operators job harder when they might already be stretched whilst dealing with a major incident.

3.5 Lack of Connectivity

When a major emergency occurs it is highly likely that the response will be by all three of the retained emergency services plus the local authority emergency planning department and any other agencies (voluntary or otherwise) that have been called upon to assist. In many incidents that have occurred in the past there has been a communications failure simply because there has been no single co-ordinated emergency communications network or the appropriate inter connection between each of the communications networks in use by each of the called services. The usual effect of this upon the handling of the incident is that some key messages between services are delayed slowing down the overall multiple service response.

This was the case in the handling of the Clapham Junction Train Crash that occurred in December 1988. Due to a lack of a common communication scheme all three services set up a temporary control station at the scene which included the services own communications facility, inter service communication was eventually achieved by a team of runners carrying messages between each of the control locations. It has since been suggested that even a network of field telephones would have been preferable. The other problem with the co-location of temporary control facilities was the radio interference that was caused to one another due to the proximity of high power transmitters to receivers.

In 1967 bushfires ravaged the southern area of Tasmania, the Island State of Australia. At this point in time the radio networks of all the services were in poor condition. One of the drawbacks to the efficient management of this incident was the lack of radio intercommunication between the emergency services themselves and with other organisations [22].

In the United Kingdom some of the more serious incidents tend to involve the transportation of hazardous chemicals, what are referred to as HazChem Incidents. It has been suggested that the handling of these incidents is sometimes hampered by the lack of common communications systems between the emergency services [23]. When dealing with a hazardous chemical certain procedures have to be adopted, them being dependent upon the chemical involved. Often such information is known by the fire brigade either from prior knowledge of the shipment or based upon HazChem identification labels upon the shipment. There is often an undesired delay in transferring this information to the dealing police and ambulance officers who may well be present at the scene of the incident.

In mountainous areas of the United Kingdom there is often the need to provide search and rescue facilities for members of the public who become injured or befall some other accident through either work or leisure time pursuits. These search and rescue facilities are provided by both voluntary and RAF Mountain Rescue Teams, often in conjunction with RAF or Navy helicopters. Any incident that occurs in the mountains involving a civilian is the responsibility of the civilian police who may well call upon the services of voluntary or RAF Mountain Rescue Teams as their agents. There exists no communication system by which a police officer on the ground might communicate directly with a helicopter involved in the search, there is no common radio channel on which such communication might take place. This lack of connectivity has caused many mountain search and rescue operations to be hindered [24].

Within the three retained emergency services in the United Kingdom (Police, Fire & Ambulance) there is available a common, single frequency radio channel that might be used by any of them for inter service communication. However, being a single channel usable by only one radio transceiver at any given time, at major incidents this resource often becomes overloaded and there is once again a failure due to a lack of inter connectivity, it is suggested that more than a single common radio channel is required [25]. Even though this facility is available to the three services it is often the case that the radio transceivers first deployed to the emergency ground are not fitted with this facility, being the transceivers used for routine daily operations.

3.6 Multiple Failure Causes

The above investigation has looked at a failure of an emergency communications network being attributable to one factor only. There are examples of where there has occurred a failure of emergency communications due to more than one of the above factors. This can be more difficult to deal with because one failure mode might be masking another and hence make recovery more difficult. Some examples of this scenario shall now be investigated.

The United States suffers from Hurricanes periodically, two notable instances in terms of emergency communications are Hurricane Hugo in 1989 and Hurricane Andrew in September 1992 [26]. In both of these cases major network resources were lost both for fixed wired networks and mobile radio networks. An additional failure was that due to the wide area of devastation, including rural areas, there were some districts that were not within range of the existing communications networks, be them operational or not.

In December 1991 a series of simultaneous road traffic accidents occurred on three major adjacent roads, the M62, the M1, and the A1 in West Yorkshire. Dense, freezing fog had surrounded this area for several days prior to and after the event. An estimated nine hundred vehicles were involved in some thirty accidents that occurred over a three and half hour period [27]. There was a break down of emergency communications for two reasons in this instance.

Due to the large number of incidents communications systems were being overloaded. The private radio networks of the emergency services were having to handle a large amount of traffic from the large number of responding units involved, this slowed down the transmission time of essential messages. Many of the public vehicles involved in the incidents were equipped with mobile phones having access to the public cellular networks. Numerous calls were being made to the local police either directly or via the 999 system to report the multiple accidents. Much of this information was either a repetition of data already gathered or useless due to the inability of the caller to pinpoint their exact location in the dense fog. This overload of useless information had a knock on effect on the emergency services, the first one being they were unable to use these public networks themselves to alleviate there own network overload. Many of these calls were tying up conventional telephone lines at police stations and local hospitals, lines that were required for other essential communication. There were also many attempted calls from cell phones in the area that simply went unconnected due to an overload of the local cellular capacity.

The second failure in this case was that of a lack of inter connectivity between the emergency services. In the emergency ground this manifested itself as police, fire and ambulance crews being within a few hundred metres of each other on blocked roads with no direct communication. They were also unaware of each others presence due to the nature of the dense freezing fog. Away from the emergency ground there was a failure of reasonable communication between the controlling police centre and local hospitals for the collation of casualty data. Some of this failure was due to the previously mentioned blocked telephone lines but there was no alternative means of communication available either.

On Christmas Eve 1990 a fire severely damaged the telephone exchange and equipment room at Corbett Hospital, Stourbridge, West Midlands; this rendered the telephone exchange inoperative, during this incident there was a failure of emergency communications for two reasons [8]. Firstly a vital network resource, the telephone exchange, had been lost which meant that there was no internal communication within the hospital and the rented landlines to the adjacent hospitals were also inoperative, with no provision for any other outside line contact.

Secondly, the provision for a minimum outside telephone service was through the use of a handful of cellular telephones using public networks. It was soon found that often all of these phones could not be used due to a lack of capacity in the nearby cellular base sites serving the hospital, the network soon became overloaded with the volume of traffic offered to it by the incident. This caused some concern to the chief fire officer dealing with the incident as a the cell phones were being relied upon for making further 999 calls should any subsequent fires break out. Normally there is an automatic link through the internal exchange and a rented landline.

Whilst the hospital was having to cope with these communications failures it also had to cope with the other impacts of the fire such as physical damage, closure of wards and loss of other facilities. At the same time it was trying to operate as normally as possible.

3.7 How The Emerging Communications Networks Will Cope

Much of the above discussion has been based upon incidents that have occurred in the past on existing emergency communications networks. Some of the radio networks referred to above are in fact based upon technology that is some twenty years old. Although the radio equipment itself in nearly all cases will be up to date and new, offering the benefits of increased performance, longer battery life, overlay paging, data transmission, to name but a few; the planning behind the network is almost certainly around twenty years old, the network has simply been updated rather than replaced with a new design.

In both Europe and America there is currently work on developing completely new emergency communications networks to answer some of the requests of the current users of emergency communications networks. These new networks should be considered to see if they are likely to fail in respect of any of the five modes mentioned above.

The United Kingdom is currently leading Europe in the development of TETRA, a pan European Trunked Radio System. The new network operates in a digital trunking switched mode thus offering increased security. A new commonly agreed frequency band is to be used for emergency services TETRA across all of Europe thus making frequency allocation easier to avoid mutual interference and opening the market to many equipment manufacturers [28 & 29].

In addition to voice communication networks TETRA will offer data communications, personal calls, group calls, overlay paging and telephone network interconnect to name but a few facilities.

In the United States The Association Of Public Safety Communications Officers (APCO) have worked on developing an open standard for emergency services communications, APCO 25 [30]. Although different to TETRA it offers many of the same facilities that are described above.

Alas, it is feared that these new networks are equally likely to fail from the five common failure modes that have been identified in the above rigorous investigation. It is true that such networks are more likely to offer inter service communication, particularly if all services are using the same modulation scheme and frequency band, but this will only be available if this particular facility is made available to the end user by the network. Such modern networks are highly dependent on cellular radio base stations and network infrastructure, making them vulnerable to the loss of a network resource. The contamination of a strategic centre is something that a network alone cannot solve but one has to consider the feasibility of moving such a strategic centre, how will such networks cope with the loss of a major switching centre? The overloading of a network is something that is possible whatever the network capacity, it merely requires the volume of traffic to be offered. It is highly likely that any modern network is equally likely to have rural areas that are not within network coverage, this is a question of economics in some respects.

This chapter has studied the modes by which an emergency communications network might fail when called upon to offer communications in response to a major emergency. Through the study of incidents that have occurred it is believed that these network failures fit in to one of five categories, categories that have previously been unidentified. These studies will now progress to investigate what solutions, if any, exist to try and prevent or cope with an emergency communications network failure.

CHAPTER 4

SOLUTIONS TO COMMUNICATIONS NETWORK FAILURE

The previous chapter has shown that it is extremely unlikely that one can design a communications network that can cope with every eventuality, particularly major emergencies. There are various ways one can address this problem and some potential solutions are discussed below.

4.1 Current Solutions to Potential Network Failure

Within Emergency Communications Networks that are currently in use there are some schemes which make networks less liable to failure in one or more of the five failure modes previously described. Although it is believed that these measures are not a complete 'cure' there is to be merit gained in studying these schemes to see by what means the network is less likely to fail. In order to provide coherency within the argument these schemes will be investigated with respect to the failure modes previously identified.

4.1.1 Loss Of Resource

One way of coping with the loss of a resource is to duplicate each of the resources that exist in the network such as switches, base station transceivers, cabling, etc. One example of this is the communications scheme that exists within the Channel Tunnel for all routine and emergency communication [31]. Every item of radio communications equipment is duplicated including the trunking switches and control rooms, one of each being located at each end. At any one moment in time only one of the systems is in use but the redundant system follows all traffic flow and operates in complete parallel so that should the primary system fail the second one can automatically take over in an almost seamless manner.

Such a scheme of redundancy is manageable for something like the Channel Tunnel as it exists along one linear path only and is fixed in size. There is never going to be a requirement to expand coverage in response to a new market or changing need that might occur in covering land areas. The Tunnel has the advantage of having two distinctly separate locations for siting vital resources, each end; in land based systems this is somewhat difficult as natural resources such as hill top sites for radio base stations tend not to be duplicated in such a way. Another factor against such pure duplication for wide area networks is the cost consideration. In such a high budget operation, like the Channel Tunnel, doubling the cost of the communications system to create duplicate redundancy is probably only a fractional increase in the cost of the entire operation. There is also a required public perception of safety in commercial operations so the increased cost in communications systems can legitimately be passed directly to the customer; something that might be difficult in the case of the emergency services.

Perhaps a more realistic example of an emergency communications network that has been designed to cope with the loss of a network resource is the flood warning scheme implemented and used by the North West Region of the Environment Agency [32]. The Agency has a network of remote sensing stations that measure important variables such as river surface level, river flow rate, rainfall, wind direction and wind speed. These figures are regularly fed back to two control centres so that the possibility of a flood may be predicted. When flood conditions, or warnings of, occur this network becomes most vital in monitoring progress to see if the conditions are likely to worsen or abate.

Consequently the data from these remote sensing stations is transmitted back to the control centres via two independent means, through the Agency's own private UHF radio network and using modems over PSTN links. As a result should either one of these networks fail the data from the remote sensing station can still be obtained. If the UHF network has failed and the Agencies computer system is not fully functioning then the remote station can still be contacted by a PSTN call from the control centre and the data obtained by manually decoding a series of tones passed by the station over the line. This example shows how the loss of a private network resource is catered for by also making use of a public network, something that is cheaper and perhaps easier than duplicating one's own private networks. An attractive point to note in this solution is the diversity involved, the two transmission schemes are reliant upon completely different technologies, hopefully this will mean that they are not necessarily vulnerable to the same forms of damage. However, the Agency is now dependant on an independent network supplier, rather than just its own scheme over which it has more control.

4.1.2 Strategic Centre Contamination

There are really only two solutions to coping with the contamination of a strategic communications centre; either permanent provision is made for a secondary centre at a completely different location or one has some form of mobile centre capability to use should a key centre be lost.

The case of the Channel Tunnel Communications scheme cited above is perhaps a good example of having more than one strategic centre, a full command and control suite is located at either end of the Tunnel with both suites connected to the duplicated communications system. The theory is that either one of the centres is in a position to take full control of any incident that may occur inside of the Tunnel, this particularly being the case if either one of the centres is unavailable for any reason. The nature of a linear tunnel once again lends itself to the easy construction of such a plan.

The concept of a mobile strategic communications centre is an interesting one and will be the subject of more rigorous investigation later. In creating such a facility it must be considered that a mobile facility is going to have less physical space and must therefore carry a reduced functionality created from the facilities that are deemed essential. One must consider how such a mobile facility is going to interconnect with the existing communications network and obviously this provision must not be through the primary strategic centre in any way. Finally storage and deployment of a mobile command centre must be considered, it would be unwise to store it next to the primary centre as any unplanned contamination might render both inoperative.

4.1.3 Overloading of Network Capacity

Currently there appear to be no simple solutions to the overloading of communications networks, if the stage is reached that all networks are overloaded it would be assumed that all available capacity has been brought into use. It is worth noting that systems which implement redundant networks where message transmission is duplicated and routed through two different routes might be configured to cope with an increased volume of traffic. In the two examples discussed above it would be feasible, in the event of a larger volume of traffic than the network can cope with, to use the second duplicate network to carry different information thus increasing the bandwidth of the overall system. To do so would be at the expense of the redundant capacity to cope with the loss of a network resource, this is something that should perhaps be considered when constructing major incident plans rather than waiting to consider when a major incident happens, causing a network failure.

A recent development in the private radio market that is undergoing testing might well help to increase the capacity of private radio systems, such as those that tend to be used for emergency communications. It has long been the practice to use mobile terminal transmitter power control in the public cellular radio systems, this having two major benefits. Firstly the battery life of portable equipment is extended, secondly frequency re-use is possible within smaller areas due to the decreased possibility of co-channel interference. It is the second of these reasons that is of interest to increasing the capacity of a network. If power control was used within emergency communications networks then frequency reuse could occur within a smaller area, this might be useful around the area in which a major incident has occurred [33].

An example of emergency communications network overload quoted earlier was that of the police casualty bureau. The overloading placed on local telephone exchanges by calls into the bureau from members of the public can make the bureau operation very slow and more importantly hamper local telephone communication that is required to deal with the incident itself. A solution has been suggested to this in the UK by using the facilities of a modern digital telephone network [18]. The aim is to set up a national police casualty bureau service that is able to be called into operation in response to a disaster. The national telephone number for this should never change although the bureau could be set up at any one of five centres around the UK, preferably the one furthest from the incident. The load diversion facilities of the PSTN at a national level are used to ensure that the minimum traffic possible is routed through the areas where the major emergency is located.

4.1.4 Areas With No Network Coverage

This is perhaps the type of emergency communications network failure that currently has the most solutions, both in the short term and the long term.

A recent development in the mobile radio market has been the introduction of position location schemes for mobile units, what generally is called Automatic Vehicle Location or AVL. The main requirement here is for the vehicle to have some form of position transducer on it so that its location may be determined, this is commonly a Global Positioning Receiver (GPS) [34] although other location technologies do exist. The determined position is then transmitted back over the existing communications network to the controlling centre. At the controlling centre the position received could be used to indicate the mobile unit location to the operator, however in this case the position data can be used to alert the controlling operator that a mobile unit is about to go out of range of the existing system. An alert can then be issued to the operators in the mobile unit that communication will be lost and to use any pre agreed contingency to cope, this might be the use of another services network or use of a public network.

An alternative approach would be that of terminal self location [35] so that there would not necessarily be a requirement to pass the data to the controlling the centre. The mobile terminal itself would be able to predict a loss of network coverage and take the appropriate action automatically or alert the mobile unit's operator.

Although AVL schemes are unable to provide communications in areas where there is no existing network coverage at least they are able to predict when network coverage will be lost. If this occurs en route to dealing with an incident for the front line vehicles at least this problem can be flagged at the outset rather than waiting to discover that there is no network coverage when urgent traffic needs to be passed.

Areas with no network coverage are often known of prior to an incident occurring, and the network operator would like to extend coverage of the network but at minimal cost. For the emergency services the largest part of the communications budget is the control centre so a solution might be in the use of a modern technique which allows one operator to operate several radio channels as if they were a single channel through using a Search, Vote and Lock scheme [19]. In this scheme the base station for each radio channel is located separately so that each covers different geographic areas that may or may not overlap and is linked to the control centre by some suitable means. All transmissions from the control centre are simultaneously broadcast on all channels, it is the receiving mobile units that scan the available signals and automatically 'votes' which is the strongest. For transmissions from the mobile units the hardware at the control centre decides which is the strongest to offer the operator. This system is automatic and hence doesn't require the mobile operators to physically change channel for their area of operation. Although using more resources this can be quite an effective way of increasing network coverage.

A more simplistic approach of increasing geographic coverage, particularly for one 'black spot' or a fringe area might be the use of a cell enhancer [36]. These devices are in fact signal relay stations but do process the transmitted message in any way like an automated radio relay station might when receiving and retransmitting a signal. In an enhancer a signal is simply received on a donor site facing aerial and re-radiated on a mobile facing aerial sometimes directly or with radio frequency translation. If operating on one frequency without translation then one must consider isolation of the two aerials to prevent feedback. Such devices can be very effective in covering additional areas but require no modification to the existing network infrastructure and do not require a permanent separate link to the network control point. If used with an uninterruptable power supply a cell enhancer could be the most reliable way of extending network coverage.

There will always be cases where a major incident occurs in an area where there is no network coverage. What is required in this case is communications equipment that is not dependant on any form of network structure, radio communications equipment that is able to operate from mobile unit direct to mobile unit; such operation is known as 'back to back' operation. The more traditional open voice channel radio systems as used by the emergency services in the UK tend to have this facility available on an independent frequency that is accessible by the operator changing channel, although this is not always the case. The police communications system around Skippol Airport in The Netherlands operated with similar technology but the mobile radio units themselves were not programmed for a back to back facility.

It is often the case that mobile radio systems within the emerging systems that tend to use trunking and digital technology do not offer any form of back to back facility, all calls are dependant on the availability of a base station or cell site. One exception to this is the RUBIS system used by the French Gendarmerie [37]. The system transmits all data in a digital format using vocoders for voice and operates in a cellular trunked radio fashion in the low VHF part of the radio spectrum around 80MHz. However it is possible for the system users to set up a direct mobile to mobile call that does not use any part of the network infrastructure, this can be done by prior agreement or automatically should the networked signals disappear. Such operation is very useful for direct communication between units when one or more them may be out of range of the network infrastructure. A rare example of back to back operation from a modern sophisticated digital network.

4.1.5 Lack of Network Inter-Connectivity

There currently appears to be little scope for solving the problem of network inter-connectivity when dealing with a major emergency, particularly at the incident scene, yet it would appear to be technologically the most simple to solve. Both of the two major emerging standards for emergency services communications, TETRA and APCO 25, seem to make more provision for this than has been the case in the past. Investigation has highlighted three simplistic solutions to this problem.

It has already been discussed that the emergency services in the UK have laid aside a single frequency in the UHF spectrum as a common communication channel between services, this being an open voice channel operated in a back to back mode. The problem with this scheme is that this part of the radio spectrum is not necessarily where the primary operation frequencies reside for all of the three retained services so not all mobile units are equipped with facilities for this frequency. Consequently when responding to a major incident deployment of additional resources is required. A second problem with this provision is that it is only the three retained services that have access to this channel, the other agencies (local authority, health, utility and voluntary) are excluded.

The UK Ambulance Services have tried to address their own problem of inter service communications, i.e. communications between units from different authorities. Although all services operate in a similar part of the VHF radio spectrum the channels are allocated in such a way so as to not cause mutual interference for routine operations. Recently a single frequency has been agreed as the Emergency Reserve Frequency (ERF) which again operates in a back to back mode so that members of different ambulance services might communicate with each other in response to a major incident by simply changing to this frequency. The voluntary first aid associations have also been given access to this frequency and may install the facility in their own radio equipment. The disadvantage of the ERF is that it is in a part of the radio spectrum that the other two retained services do not have access to.

A solution to this problem, that of inter-service communication, has been sought in the Tasmanian Emergency Radio Plan [22]. In the Tasmanian solution all of the emergency services, voluntary agencies, local authorities and some prominent large forestry companies communicate on similar but separate radio frequencies and share a common channel numbering scheme. Hence, a member of one service can simply switch their transceiver to the radio channel of another service for direct communication as all channels operate in a back to back single frequency mode. However, this solution proposed for the small island state of Tasmania may not be suitable for somewhere like The United Kingdom where there is a larger population to serve and larger retained services.

All three of these inter service communication schemes hinge on the use of back to back open voice channels, often only one. Such a resource can very quickly become overloaded within an emergency ground so a key question in dealing with emergency communications network failure must be how can this situation be improved?

4.2 Constructing Networks That Are Tolerant To Possible Failures

The above section has described various schemes that are currently available within existing emergency services communications networks to help them cope with major incidents and hopefully prevent a network failure. However, it is felt that none of the above measures prevent a failure from all of the methods presented in the previous chapter. It is believed that to use a combination of the facilities described above may well help to produce a network that is much more capable of coping with the quantity and urgency of traffic that follows a major emergency, if constructed carefully. In order to study this the following section will theorise as to how one might construct such a network.

4.2.1 Robust Fixed Communications Networks

Previous examples quoted above have shown the merit to be gained in diversity of communications means, one such example being the system employed in the North West Region Flood Warning Scheme. Here the term 'robust' is used to mean a communications network that has more than one way of passing a message.

To construct a robust network one would actually make use of many different forms of communication on both public and private networks with them being both wired and wireless. The aim is to duplicate channels of communication but with the duplication being in different technologies. Modern technology makes available a whole variety of communications means, a robust communications network should have access to all of them.

It is this argument that is put forward by Patterson [26]. Here he suggests that the emergency services should have access to all means of communication. When a major emergency occurs it is inevitable that some of these means will fail but this being the case one just makes use of the other means that are still available. Should a network be unavailable then one just makes use of another, alternatively should a network be overloaded one reduces the load by using another to provide a parallel route. Effectively the plan is to make the best operational use of those networks that remain available after a major emergency has occurred. An interesting point made here is that increasing use will be made of the internet for emergency communication purposes.

The disadvantages of such a plan is that for this to work effectively all emergency services personnel require prior knowledge of all the communications networks that are available. They need to know how they operate, how to make the most effective use, when to recognise that they have failed and how to decide which network is best to use in which circumstances. Such a scheme is dependent on both public a private networks, some being owned by the emergency services and some by network providers. The cost involved in setting up such a scheme is likely to be very large in the first place given that a large diverse range of equipment needs to be purchased, even on going standing charges if the equipment is not used will be significant.

This scheme has definite merits in that it does address all of the five failure modes described earlier, however disadvantages have been highlighted too. This work will continue to investigate other possible solutions.

4.2.2 Redundant Communications Networks

To produce a redundant communications network one simply duplicates some or all of the existing communications network, then should any part or the whole of the existing network fail the redundant network is able to take over and still provide the users with a reasonable grade of service.

The ideal scenario would be to duplicate the entire communications network so that the reserve network may actually be operational all of the time precisely mimicking what the primary network is doing. When a failure in the primary network occurs it is then much faster for the reserve network to take over, possibly even in a seamless manner.

An example of such a system is the Channel Tunnel communications scheme that is discussed above [31] where the entire communications network is duplicated and the two networks do operate in complete parallel so that a failure causes minimum disruption. A facility such as the Channel Tunnel lends itself very easily to the installation of such networks due to it being limited in size and linear in nature, producing a redundant wide area network covering a large terrestrial area is a much more formidable operation being technically and economically very difficult to achieve.

Constructing such redundant networks is possible, even if difficult, but their provision would certainly make emergency communications networks more reliable in the event of a major emergency. Should a network resource be lost the second network can be used to bridge the gap, a redundant strategic communications centre can be used should the primary one be contaminated and should the primary network become overloaded then the second redundant one can be used to provide additional traffic capacity. However, a second redundant network does not help the existing network to penetrate uncovered areas or provide additional inter-connectivity not available in the primary network, so it would initially appear that redundant networks are not necessarily the answer to all of the five failure criteria suggested earlier.

An alternative approach to redundant networks might be to consider mobile redundant resources. Rather than replicating an entire network one simply reproduces some key universal network resources that can be moved to an area to help or replace an existing network resource in the response to a major emergency. A rather unique example of such a resource can be found in The United States, the National Transportable Telecommunications Facility (NTTC) was deployed for the first time in response to Hurricane Andrew in September 1992 [26]. The NTTC is a bulk transport aeroplane containing 15 channel public cellular telephone base station which is coupled to a private branch exchange (PBX) for within cell calls. The PBX is coupled to the main PSTN via a satellite link on COMSAT and INTELSAT. Also coupled to this communications system is a UHF two way radio system offering both trunked and single channel capabilities with a telephone patch interconnect available. When operating the NTTC can provide effective communications in an area of around 25km radius.

Although a very expensive, unique resource, it is highly likely that such a unit can help to alleviate an emergency communications failure that has occurred due to any of the five failure criteria previously identified in this work. The philosophy behind this resource represents a shift in thinking away from traditional fixed network resources to temporary, mobile resources. It is believed that these studies show the provision of a fixed network to cope with the traffic of every major emergency is extremely difficult if not impossible. The way forward is to investigate how one might use temporary communications networks to create communications scheme that can cope with a major emergency. Being temporary such networks can be deployed in a way that is most useful at the time and can dynamically change in response to the users' needs.

4.2.3 Temporary Communications Networks

A solution to many of the problems discussed above might be in the use of temporary communications networks to operate alongside existing fixed networks, to offer additional traffic capacity, or to provide the link between two points that currently does not exist. Alternatively, temporary communications networks may be used to replace a network that has failed in a major emergency, or to create a network that never actually existed in order to get vital traffic to and from the points where it is needed.

The need for such a temporary network will not be discovered until an emergency has actually occurred and it is found that existing fixed networks are not coping with the emergency traffic. Hence, a major feature of such temporary networks is that they must be quick and simple to establish. Consequently temporary networks are likely to have a high dependence on radio technology in order to maintain their portability. It can be seen that the equipment for constructing such networks should be easily accessible, if not already in the possession of the services requiring its use.

It is extremely likely that the equipment that is used to set up a temporary communications network may be exposed to a hostile environment, either caused by natural weather conditions or by the emergency itself. Much can be gained from the situations that designers of rural communications systems have had to cope with. Although rural communications networks are often not temporary installations there are many similarities that can be drawn between the requirements of such networks and temporary emergency communications networks. The main one being a reliable communications network for a relatively small number of users where a provision for connection to existing fixed networks does not exist.

To justify this argument there is merit to be gained in investigating how temporary communications networks might have helped some of the examples of emergency communications network failure cited in the previous chapter.

The earthquake that struck the city of Newcastle in Australia destroyed many key network resources. A temporary communications network could have been set up after the earthquake, using both short and long range radio communications, to provide connectivity to those places that had been isolated due to a resource failure.

The Pipa Alpha incident suffered an overloading of existing networks that were in use for all the communications. Temporary radio networks could have been set up between all of the fixed points in the incident such as the rescue co-ordination centre, coastguard stations and oil platforms so that traffic between these points could have passed on this temporary network. This would have relieved the load on the existing networks that necessarily had to be used by the mobile resources such as ships and helicopters and allowed message transfer to be faster.

The Strahan Bay mass whale stranding incident in Tasmania suffered a lack of connectivity to existing networks due to its rural isolation. The provision of a single temporary long range radio link from the bay to a communications centre within the nearest large settlement would have alleviated the problems encountered here.

The multiple road accidents that occurred in dense fog in West Yorkshire could have been helped by two separate temporary communications network provisions. A facility for the different services to communicate with each other over a short range would have alleviated the problems on the roads themselves. The setting up of an independent temporary communications networks between the main police control centre, those of the other services and the local hospitals could have been used for the collation of casualty information, data that was unable to pass on conventional phone lines due to blocking. A data network would have best suited this application.

Again at the Hillsborough incident a temporary data network between the local hospitals and other controlling centres would have enabled vital casualty bureau data to be passed that was blocked on existing telephone networks.

4.2.4 Emergency Ground Communication

From the evidence that has been gathered it has been discovered that during a major emergency, if a communications network failure occurs, the failure is more often than not localised to the actual location of the emergency as opposed to being a widespread failure. This may happen because existing communications networks in the area may have saturated (this is often seen in the cellular telephone network) or may not actually penetrate the emergency ground. However, the remainder of the communications network will probably be intact and fully operational.

There is scope for the use of local temporary communications networks that carry vital traffic from the emergency ground to a point where it may join an existing communications network and vice versa. The provision of a local communications network may well alleviate the problem of inter-service communication within the actual locality of the emergency. This will remove the need for traffic to pass between personnel via their own respective control centres, thus costing what may be vital time and causing congestion on signal paths; the traffic may now pass directly. This is a facility which must be used with caution so that the controlling centre is not 'left in the dark', nonetheless, if used correctly, it can be of great benefit.

Any proposed solution to the above investigation must, of course, be portable and swift to implement although being physically in a local area speed of implementation can be kept to a minimum. One would have to fully consider the engineering, managerial and philosophical aspects of such temporary networks.

Once again it will be considered how such temporary emergency ground networks may have helped incidents cited as failure examples previously.

In the incident that occurred in Amsterdam near Skippol Airport the police lost all local communications due to the loss of their local base station radio. A temporary radio network set up in the locality could have been used by the police to re-establish their own communications channels. If the other emergency services had access to this temporary network at the incident then inter service communication between all of them would have been effective within the emergency ground too, thus speeding up joint services decisions and co-ordination.

At a large HazChem incident the provision of an emergency ground temporary network would aid inter service communication and hence the flow of important chemical information to all emergency personnel involved in dealing with the incident. It is often the transfer of this information that is hampered in these incidents. Such emergency ground communications systems would also aid direct communication between police forces, RAF helicopters and mountain rescue teams when dealing with incidents in mountainous areas of the UK.

The incidents at both Lockerbie and Corbett Hospital in Stourbridge, West Midlands demonstrated the need for a temporary communications network within the emergency ground to replace a network that either didn't exist or had failed and to provide inter service communication. In responding to both of these incidents RAYNET did in fact set up temporary voice communications networks which generally satisfied the needs. Although in the case of the Lockerbie incident the time required to set up the network was perhaps longer than desired.

Finally, the incident that occurred at Clapham Junction is perhaps one of the best examples of the merit in setting up a temporary communications network within an emergency ground. Due to a lack of inter-connectivity all three of the emergency services set up a temporary control centre at the incident, each with its own communications facility which caused interference with each other. Very quickly the failure of an ability for inter service communication was identified, this need eventually being satisfied by runners carrying messages between each of the temporary control centres. Without realising it the services had set up a temporary communications network to satisfy the need, albeit made of human runners, it is this idea that needs to be advanced and developed into a technologically more elegant solution.

This chapter has investigated the means by which the failures in emergency communications networks that occur at major emergencies might be solved. The methods of preventing failure and responding to failure have been investigated. It is believed that developing a communications network that will never fail is extremely difficult, particularly given that major emergencies are unpredictable and their communications requirements simply not known until they occur. Therefore this work suggests that the solution is to be found in temporary networks that are set up in response to the major emergency to satisfy the communications requirements that are not satisfied by existing networks.

CHAPTER 5

A STUDY OF TEMPORARY COMMUNICATIONS NETWORKS

This chapter shall briefly consider some of the types of temporary communications networks that might well be set up in response to a major emergency as a result of, or maybe even prior to the failure of existing emergency communications networks. All of these networks are based around radio communication systems in order to maintain portability and mobile communication.

Often such networks will be simple in their design and technology, this being necessary for them to be swiftly established with the minimum technical resources which does not require the movement of large quantities of plant. In the majority of cases it is only a simple network that is required in order to pass messages that have failed on an existing overloaded network, to provide minimal interconnection where none previously existed or pass messages between areas with no existing network coverage.

The primary requirement for such temporary communications networks is for voice communication as this is the natural mode by which humans commonly communicate in emergency situations and requires the minimum of manual dexterity with the communications equipment; this is particularly true in the earlier stages of a major emergency.

Various schemes for temporary communications networks shall now be considered in turn, starting with the simplest voice network and progressing to more complicated wide area coverage networks that might be for voice or data. A major emergency might use one or more of these schemes simultaneously. Alternatively a simple network might be set up initially which evolves into one of the more complicated examples below as the emergency becomes protracted or its communications requirements change.

5.1 Open Channel Back To Back Networks

In this, the simplest of schemes, all radios that take part in the network transmit and receive on a single common radio frequency (channel) such that voice communication is direct from radio to radio without the need for any network infrastructure. Scheduling of messages is performed by the radio operators themselves by strict adherence to recognised voice procedures.

Such networks are very quick to set up and as such form the backbone of the mobile communications resources used by the voluntary emergency services [4]. Open back to back networks can be very effective and most radio equipment in common use can have this facility built in so that by the simple operation of an operator switch the radio departs from its normal network infrastructure and becomes part of such a network on an independent radio channel. Using routine radio equipment for use in such a network has the advantage that such a network can be established within an emergency ground without the deployment of additional resources.

Conversely, one might choose to use independent radios that are deployed at a major emergency when required for building a back to back network. The advantages gained are that the independent radios could operate on a different frequency band to minimise interference to existing networks and have a physically different appearance so that they may be quickly identified at a major incident. This might be a suitable use for the modern narrow band voice technologies recently developed [38].

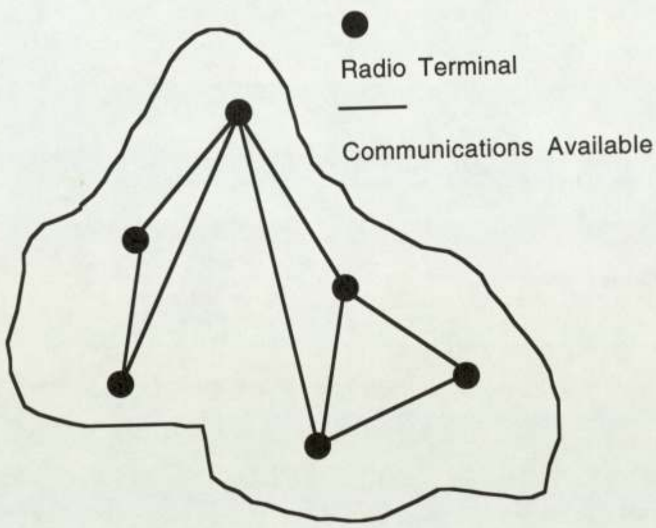

Figure 5.1 - A Typical Back to Back Open Channel Network

The disadvantages of such networks is that the communications range between radio terminals is very limited, particularly when using hand held devices, consequently such a network might only be used to cover the emergency ground itself, even if that is feasible depending upon the size of the incident. The limited range can lead to operational difficulties given that all transceivers might not be able to hear all traffic, i.e. it may not create an all informed net.

When using vehicle mounted or building installed radio transceivers communication range can be much greater for the VHF frequencies typically used, and in this mode such networks might be used for providing interconnections that did not previously exist or to provide a link between existing networks and an out of range emergency ground. In the latter case one might use two back to back networks, one for intra ground communication and one for inter site communication.

5.2 Single Repeater System

The use of a single temporary repeater is an extension of the above open voice network. In this scenario one sites a single radio relay station in a favourable location that is capable of communicating directly with every location requiring the temporary network; typically this would be a high spot within or close to the emergency ground. All radio signals now pass through this single temporary repeater with all mobile outstations transmitting and receiving on a reverse pair channels to the repeater. Such a network is capable of covering a wider area and helps to produce an all informed net so that all mobile terminals may receive all traffic.

A single temporary repeater would not normally be used to provide long haul communication but to provide more reliable communication within a given area, such as an emergency ground and maybe to a single well sited point outside that could be an advance control point.

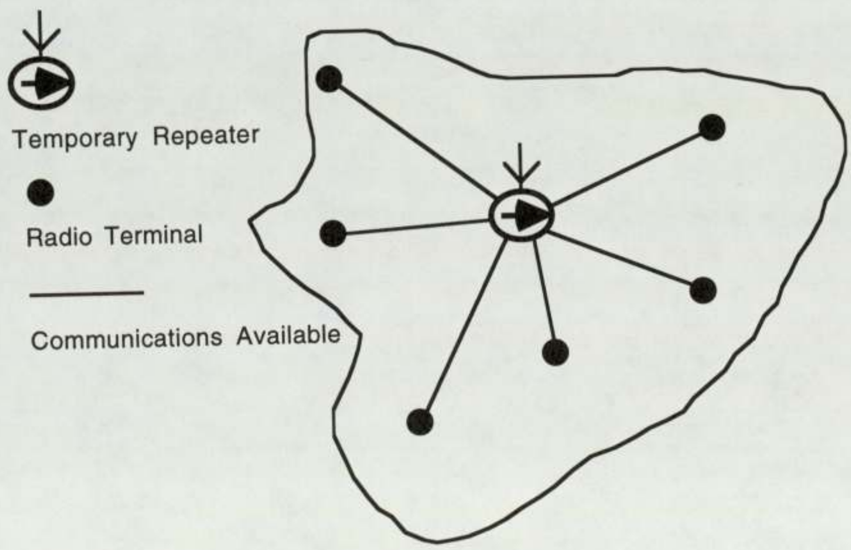

Figure 5.2 - A Typical Single Repeater Network

This network is more complicated that the simple back to back network and takes longer to install as a suitable repeater location needs to be identified and the hardware installed. The whole network is now dependant on a single critical resource that might be vulnerable to failure for a variety of reasons, although hopefully not the incident itself as one would now be in the response phase. It is necessary too for all outstations to have communication with this one single point.

Such a network might well be used to cover an emergency ground whether it has good external communications or not, there are operational advantages to intra ground communications being routed via a universally available separate network.

5.3 Temporary SVL system

One might set up a temporary "Search, Vote and Lock" network (SVL [19]) to provide a wide area coverage scheme over several, or a very large single, emergency ground and to remote control points.

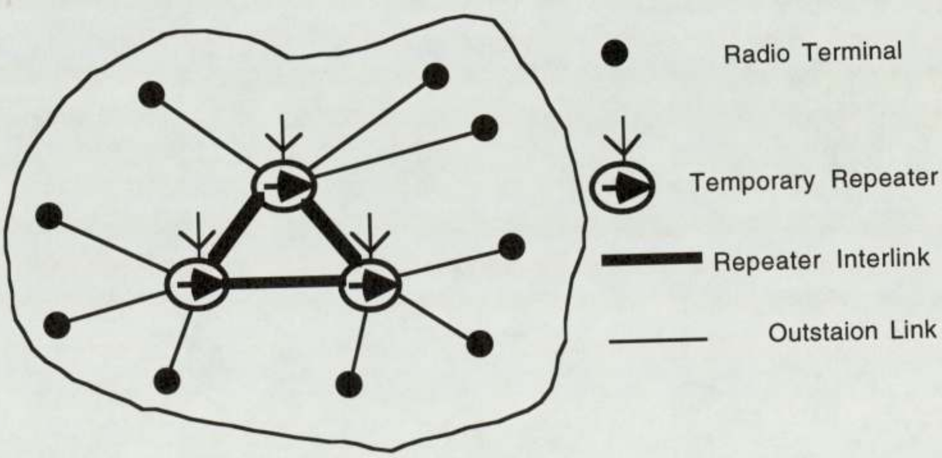

Figure 5.3 - A Typical SVL Network

To create such a temporary scheme one would have to use several interlinked repeater stations which could be used to create a wide area all informed net or a wide area directed net (each mobile terminal may only communicate with the control point). The interlinking of the repeater stations would have to be on independent radio frequencies to those used by the outstations. The SVL aspect of the system, where the mobile outstation searches and locks onto the best serving local repeater, could be performed by the mobile terminal automatically, in common with it's fixed counterparts, or manually by the operator by simply switching to the radio channel providing the best signal.

Using such a system would require a longer set up time as the problems highlighted in the single repeater system are multiplied by the number of repeater station in use. It is highly likely that such a system would be set up in the secondary response phase of an emergency that is protracted.

5.4 Temporary Extension To An Existing Network

One might use a temporary extension to an existing network to connect an area, such as an emergency ground, currently outside the coverage of the existing network in use. In order to do this one has to identify a location that is capable of communicating with both the existing network and the desired extension area. At this location could be installed a relaying node that is either a temporary repeater station or a signal enhancer [36].

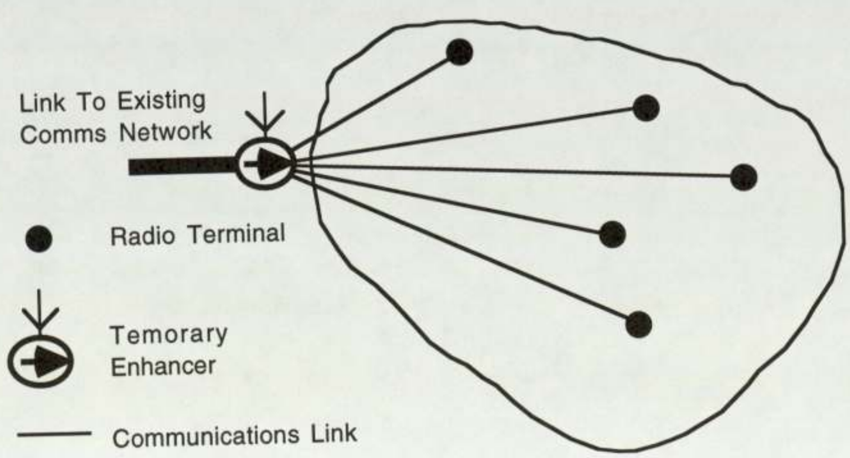

Figure 5.4 - The Use Of Enhancer To Extend Network Coverage

The requirements of this relaying node are that to the existing network it must appear as a mobile station and to the mobile station it must appear as an existing base station. This is probably easier to achieve with an enhancer that may or may not involve frequency translation, but such devices require careful set up so as not to promote any form of instability occurring within the enhancer that might block communication altogether. Consequently only certain types of enhancer could be used in such a scenario.

If set up correctly such a temporary network extension could be very effective and enhance operational efficiency as the services' everyday networks have simply been extended to the emergency ground thus appearing transparent to the operators.

5.5 Temporary Data Networks

A data network is likely to be needed to fulfil one particular role in the response to a major emergency and is likely to be required in a secondary phase. As described earlier, the primary requirement in the initial response phase is that of immediate, real time voice communication. An example of a single role that might require a temporary data network could be in the collation of data from various sites to provide input to a police casualty bureau.

The simplest way of providing a temporary data network would be to use back to back communication between mobile data terminals which might be dedicated data radio transceivers or a conventional voice transceiver used with a modem; thus creating the data equivalent of the first network described in this chapter. One would have to use a protocol, such as AX25, that is capable of being used on an open radio channel and hence can cope with errors and collisions.

As there is not the same real time requirement for most data, as is the case for voice, any mobile data terminal in such a network would be capable of performing store and forward operations too, thus increasing the effective communication range of those terminals on the fringe of the temporary data network. In fact one could site a terminal to perform such a task at a locally favourable location to act as a temporary repeater for all traffic. The advantage over its voice counterpart is that this form of repeater (what might be dubbed a digipeater) is merely constructed from a standard mobile terminal and requires no specialist equipment, something that is desirable in terms of swift installation and repair by substitution if necessary.

The disadvantages of such data networks is that the equipment for mobile and fixed terminals tends to be larger than that for a basic voice terminal, due to the requirement of keyboard, screen etc., and requires operator skill for efficient, fast use. It is believed that such a temporary data network would be most efficient when used to connect fixed points that are using some form of intelligent terminal software tailored to the task in hand. Although the network might well be used in fixed locations it is still a temporary one if it has been installed for the purposes of dealing with the emergency and is likely to be providing communication links that currently do not exist in fixed networks.

5.6 How New Technologies Can Be Used In These Schemes

In Western Europe it is proposed that all emergency services gradually migrate to the use of TETRA communications schemes that operate within a commonly agreed frequency band. As a result of input to early discussions from this and other work, the original TETRA specification was modified to include the facility of back to back communication between mobile terminals without the need for network infrastructure, in much the same way as the French RUBRIS system can.

Therefore, it is believed that TETRA transceivers can be used to construct all of the temporary network topologies that have been presented above. All of the responding services will be using common radio equipment that is programmed to the particular needs of the services. A simple reprogramming of these transceivers would enable them to operate in such schemes, it is this suggested reprogramming that is discussed later in this work.

As the proposed TETRA networks operate in the digital domain using vocoders for voice transmission then the provision of temporary data networks is equally viable.

Following from the previous presented belief that the only practical method of coping with communications network failure during major emergencies is in the use of temporary networks; the above discussion has presented some of the network topologies that might be used, highlighting their advantages and deficiencies. It is also believed that such temporary networks will be easier to construct with the proposed migration to TETRA networks for emergency services communication.

CHAPTER 6

RADIO RELAY STATIONS

Radio relay stations are a facility used within radio communications networks to extend the range of communication. They might be fixed and permanent in their nature or a temporary facility installed to cope with a major incident. This chapter considers the construction of such stations for voice communication, which might well be used to put into operation some of the temporary communications networks described in the previous chapter.

A radio relay station or repeater is an unmanned slave station consisting of a receiver coupled to a transmitter, which uses an in-built control system usually called the 'logic'. The intention of a repeater is to increase the available communication range between radio users that are usually mobile or between a fixed and mobile station. This logic controls the operation of the repeater, allowing only signals to be relayed that are of intelligible quality, transmitting the repeater's identification, and usually limiting the talkthrough time to a predetermined time limit. It would be a waste of power and lead to decreased reliability if the repeater were left in permanent transmit, so the logic arranges that the repeater's transmitter is only switched on when a valid input signal appears at the receiver for re-transmission.

6.1 Repeater Control Logic

This investigation of repeater control logic included the construction, commissioning and evaluation of prototype systems. In order to enable this to take place a suitable testing ground with understanding users was required. To this end extensive use was made of amateur radio frequencies with the prototype repeater being installed on Edge Hill in Warwickshire operating in the 433MHz amateur band with callsign GB3EH. This was found to be most suitable and was easily available to all concerned, being licensed radio amateurs.

In the United Kingdom there are a large number of amateur radio repeaters that are fully operational all year round. These may be of invaluable use in an emergency to RAYNET in an area where a repeater station has good coverage. However, it could be desirable that the control logic in a repeater station could be changed in times of emergency or perhaps change itself in response to external events such as mains failure (in this example, the transmitter may reduce its output power to conserve the back up battery and the logic informs the users by some suitable means that this has occurred).

This consideration has been addressed in this research which has led to the development of a modular repeater station control logic based around the Z80 microprocessor, which interfaces to the radio equipment via the CAIRO-8 standard. Some time has been spent in developing a minimum repeater logic based around this modular approach, but not using the microprocessor control. Instead a control card was developed around simpler technology using counters and timers. The intention is that this minimum logic may be installed in a repeater station in order to get it operational. The station may then be upgraded at a later date to incorporate all the facilities offered by the microprocessor control.

This approach to installing the repeater station control logic is very desirable as it follows the philosophy behind the CAIRO scheme. If the logic circuitry connects to the radio system via a CAIRO-8 interface then it becomes simply another active CAIRO module. The radio equipment may then be used for other purposes in addition to being a repeater station as any other CAIRO equipment may be connected to it in place of or in addition to the logic circuitry. This may be desirable when setting up or testing the radio system or may even prove useful during a major emergency when the radio system can be 'given over' to some other purpose other than being a radio repeater by simply plugging in other CAIRO equipment. However, the most obvious advantage is that of 'repair by substitution'; if a logic system is to be updated or fails then another temporary logic system can be put in its place by a simple changing of CAIRO plugs.

The CAIRO philosophy is extended to the nature of the logic system itself with the introduction of a modular style of construction. The system comprises of a few Eurocards which communicate with each other via a common TTL bus. Hence the cards can be replaced or changed with others that offer different or improved facilities by simple substitution, knowing that all cards follow the same common connection format. Once again there is the obvious advantage of swift repair by substitution. This principle allows builders of repeater logic control systems to implement their own personal designs and ideas so long as they follow the laid down standards, a principle that has been shown to work well within the CAIRO scheme.

Each section of this modular construction shall now be described in turn, with the interconnection of the modules being shown in figure 6.1. The full constructional details of these modules is fully documented elsewhere [39].

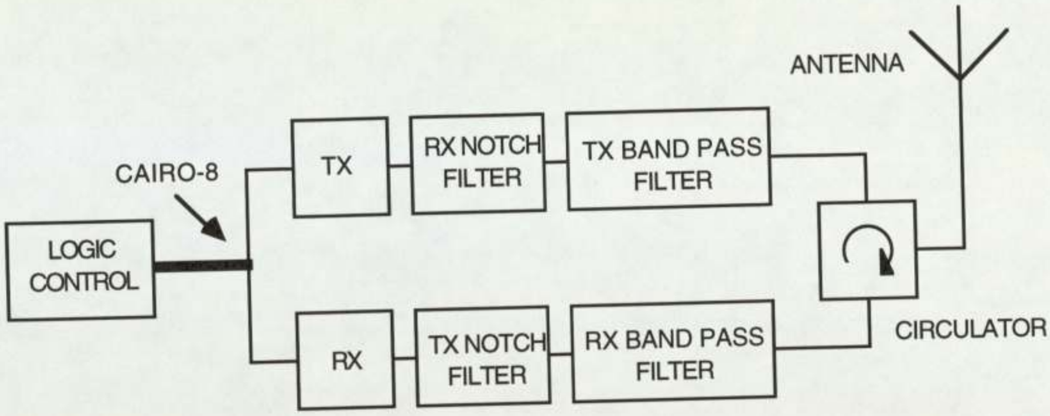

Figure 6.1 - Block Diagram of A Repeater

6.1.1 Radio Transceivers

In order to build a voice repeater station in the fashion described above it is first necessary to have a transmitter and receiver pair that is furnished with a single CAIRO-8 socket for all interfacing and control of the radio equipment with regard to baseband interfacing. This transmitter receiver pair will differ from a conventional two way radio transceiver in that it must be capable of full duplex operation, that is to say that the transmitter can operate whilst the receiver is still receiving. This has implications in the Radio Frequency Domain which are discussed below but it is worth noting that the CAIRO interface is perfectly capable of controlling simplex, semi duplex and full duplex radio equipment.

Other features of this transmitter receiver pair are that it must be stable in all respects in a wide variety of environments with the transmitter capable of continuous operation without overheating. It would also be desirable if the radio plant were powered by an uninterruptable power supply, especially if it is to carry emergency communication traffic.

6.1.2 Radio Frequency Considerations

The radio frequency considerations of the transmitter receiver pair are not strictly part of the CAIRO domain for control but do warrant brief mention here; particularly as it might require the use of large filter units which might not be that mobile when wishing to install temporary repeater stations.

Given that the transmitter and receiver must be capable of continuous operation then it is necessary for the transmitted signal not to interfere in any way with the operation of the receiver. This leads to a filtering requirement between the RF output of the transmitter, the RF input of the receiver and the antenna(s) to provide appropriate isolation. The quality of this filtering will be dependant on the frequency separation between the transmission and reception frequencies. In the case of amateur radio repeaters the separation is spectrally small leading to the use of cavity filters.

For the antenna considerations, it is desirable to use a circulator or combiner between the transmitter, receiver and single antenna in order to get a reciprocal transmission reception footprint; however, this requires better quality filtering. An alternative approach is to use two separate antennas for the transmitter and receiver that are physically separated to assist with isolation.

6.1.3 ATIC card

The Audio & Tones Interface Card (ATIC) is the first of the two cards in the logic control system developed in this work. It forms an interface between the mostly analogue domain of CAIRO-8 and a digital domain of TTL input and output signals for control by a state machine. The TTL outputs from the card indicate the current status of the receiver and provide a 50Hz clock signal, the TTL inputs to the card are used to control the repeater's transmitter; functions such as placing it into transmit, injecting one of six tones into the transmitted audio and enabling a through audio path between transmitter and receiver for the re transmission of the received signal. These TTL signals are tabulated below in table 6.1.

	DIGITAL INPUTS TO ATIC
KEY	Place the transmitter into transmit
EAR	Enable Audio Relay, the through audio path
TL-M	Tone Level Medium, for injecting loud audio tones
TL-L	Tone Level Low, for injecting quiet audio tones
MUX-3	Tone pitch select MSB
MUX-2	Tone pitch select
MUX-1	Tone pitch select LSB
STROBE	Inject the selected tone through the selected coupling level
	DIGITAL OUTPUTS FROM ATIC
TONBST	A 1750Hz tone detected on the received audio
VOX	User speech detected on the received audio
SQLCH	The receiver squelch is open detecting an RF signal
CLOCK	Crystal based 50Hz clock

Table 6.1 - The TTL Signals of The ATIC

The control of the through audio path and the tone injection is achieved by an opto isolator method developed within the scope of this work and is fully documented in Appendix 1. The coupling of the two cards, ATIC and state machine, to from the complete repeater logic is shown in figure 6.2.

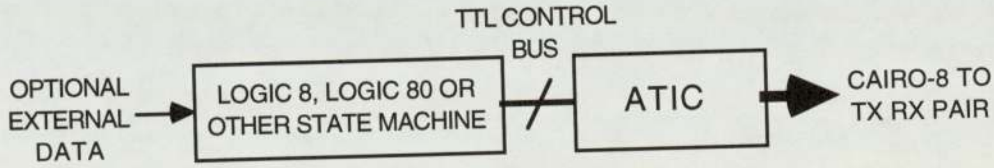

Figure 6.2 - Coupling of the ATIC & State Machine Controller

6.1.4 Logic 8 Card

The Logic 8 was the first of the state machines considered to control the ATIC. It is a standalone unit that merely interfaces direct with the ATIC's TTL signals. Using these signals it controls re transmission of a valid received signal with a predetermined time limit and periodically it generates an automatic repeater station identification sequence, using Morse Code in the amateur case.

The Logic 8 card is mainly constructed using a set of timers with some counters for timing longer periods. It is a very simple design and has proven to be most reliable in long term operation. It is suggested that every CAIRO-8 repeater control logic should have one of these cards, if only as a standby unit in the event of another more complicated state machine card failing. It might also be used to return the repeater to simple operation in the event of having to handle emergency traffic.

6.1.5 Logic 80 Card

The Logic 80 card is still undergoing development but essentially is a single board Z80 microprocessor system that uses a parallel interface controller to communicate with the ATIC. Consequently the state machine function of the Logic 80 card is performed in software. An advantage of such a system is that it might be used to interface to other external systems such as real time clock module for accurate timing, weather monitoring equipment to inform users of current conditions or the repeater station power supply system to warn users when operation from battery is occurring due to a supply failure. The data provided by these external systems might well be used to modify the state machine's operation in some way.

6.1.6 Other Logic Systems

During this logic system development other state machine designs were considered, mainly using programmable logic of some form. The method by which the state machine card is achieved is purely a matter of choice for the particular system designer, the only requirement is that the interface conditions with the ATIC are met.

6.2 Repeaters With Emerging Technology

Although this particular work was aimed at analogue technology voice repeaters, the repeater control system described here can be used to interface to other forms of radio technology providing that the appropriate CAIRO like audio interface can be made available. Consequently the principles in the above study can be used to good effect on newer systems.

An interesting prospect would be the construction of a stand alone repeater with the above logic using a single TETRA transceiver as the transmitter receiver pair. This would not require the bulky radio frequency isolation described earlier if one was to use transmit and receive channels in different time slots of the TDMA scheme. This repeater would be very easy to install, simply plugging in a control logic unit into a vehicle mounted transceiver parked in an advantageous location, and could be used in a single repeater temporary network described in the previous chapter. The mobile outstations would of course have to be suitably reprogrammed to use this network, as this work proposes next.

CHAPTER 7

THE 'SMART' RADIO TRANSCEIVER

Emergency services in the United Kingdom each have their own radio networks which are adequate for everyday operations; but during a major emergency there is seldom a capability for inter-working between these networks or the ability to construct temporary networks using resources shared by the services. The primary incompatibility lies with the radio equipment itself which varies between the various services, or even between different regional groups of the same service. There is scope for the development of a common radio transceiver for use by any service, but which is programmable to the needs of the particular using service. If such a transceiver were available and it had the facility to be reprogrammed quickly, either by a smart card or 'over the air', then it would become a flexible resource using the most appropriate radio network in use at the time of a major emergency. This may be an existing network or a temporary one that has been constructed to cope with the current emergency.

Having developed the specification for a smart radio transceiver one can then study how it might be used to implement temporary emergency communications networks which may require the transceiver to perform a very different functional role.

7.1 Current Emergency Radio Equipment

As stated above, the majority of emergency services' communications networks are based around radio networks in order to achieve mobile communication. However, there is no 'standard network' that is used by the United Kingdom emergency services, either between the services or different regional groups of the same service. The primary incompatibility lies with the radio equipment itself there being no standard radio transceiver or transceivers that are used by the emergency services. This situation has arisen due to the varying needs of the emergency services throughout the country, and leads to problems during a major emergency because there can be no sharing of equipment or network resources in order to construct the temporary communications networks that may be required.

Currently there is even no compatibility with items as straight forward as antenna connectors, power connectors and audio connectors. The standardisation of audio connectors has been the primary objective of The CAIRO Scheme [7] (Communications Audio Interface for Remote Operations) in order to aid the swift setting up of temporary radio stations and networks in addition to allowing the quick repair of audio apparatus by simple substitution.

If one was to set up a temporary communications network at a major incident then it would be desirable to use the radio equipment that is already in use by the emergency services rather than issuing the personnel with different equipment. If the existing issued radio equipment was used to set up the required temporary network then one would not waste vital time by issuing new equipment. This is obviously economically desirable as a large amount of capital could be 'wasted' in purchasing equipment that is very rarely used. Clearly, there is scope for the development of a common radio transceiver for use by any emergency service, but which is programmable to the needs of the particular using service.

7.2 The 'SMART' Radio Transceiver

The 'smart' radio transceiver is a conceptual idea that hopefully would meet the current and future needs of the users of emergency radio networks. It would be a common radio transceiver usable by any emergency service but programmed to the needs of the particular using service. If such a transceiver were available, and it had the facility to be reprogrammed quickly, then it would become a flexible resource using the most appropriate radio network in use at the time of a major emergency. This may be an existing network or a temporary one that has been constructed to cope with the current emergency.

The radio transceiver could be reprogrammed by one of two ways, locally or remotely. Local reprogramming could be achieved by using some form of data storage device such as a smart card that could simply be inserted into the radio transceiver before switch on. Remote reprogramming could be achieved by means of an 'over the air' data signal although one would have to use a very efficient code or send limited amounts of reprogramming data so as not to occupy valuable air time.

In developing such a transceiver one would have to ensure that all of the current needs of emergency radio network users are fulfilled. This would mean that in addition to simple voice communication the transceiver would have to cope with facilities such as data communication and selective calling.

An immediate benefit of all services adopting a common radio transceiver would be that of swift repair by substitution. An inoperative radio transceiver could be replaced by one from any source (not necessarily from the same emergency service) and simply reprogrammed by a smart card to replace the transceiver taken out of service.

7.3 Technical Requirements of The 'SMART' Transceiver

It is fair to assume that the smart transceiver must have a capability for voice communication. Voice is the natural means by which humans communicate with each other, especially when immediate information is required in an emergency situation. The advantage of voice communication is that it is immediate and the operation of a voice transceiver requires only basic equipment dexterity. Although other features are desirable, real time voice communication is a facility that cannot be compromised.

The technology to build a smart transceiver as envisaged here currently exists, it is merely the implementation of the technology that is novel. The transceiver could be based around a synthesised frequency agile radio transceiver. The concept of making the radio unit smart is derived by implementing a more sophisticated digital control mechanism than is currently encountered on two way radio systems. One encounters sophisticated digital control systems in the emerging radio technologies that are being used to implemented the next generation of personal communications, for example the GSM cellular telephone system.

The basic radio transceiver should be based around a FM voice transceiver designed to operate with a 12.5kHz channel spacing (for European markets). This has been chosen in order to maintain compatibility with the radio technology that is in use by the emergency services. It would be possible to use alternative modulation schemes, for example an all digital scheme like that used in the GSM system, but this would involve a complete replacement of all the current radio technology used by the emergency services if this idea were adopted.

The radio transceiver would be 'managed' by a control system that would initially be programmed by a smart card and possibly reprogrammed by data that is transmitted to it 'over the air'. This system would be responsible for controlling all of the facilities that the transceiver offers its user in addition to controlling parameters such as frequency of operation and signalling formats to be used.

The transceiver should be capable of handling all of the selective calling formats that are currently encountered such as sub audible tones, five tone systems and trunked radio system data. All of these selective calling systems would be controlled by the digital control circuitry which would be programmed to the signalling system in use at the time, if any.

It has been assumed that there will always be a requirement for voice communication over emergency communications networks, however, major emergencies also tend to create a large volume of traffic that is best suited to data transmission. Hence the radio transceiver should also contain a modem for data transmission. A suitable form of data transmission would be to use a 1200 baud packet protocol conforming to the MPT1317 specification [40] that is physically accessed via an RS232 serial port mounted on the radio transceiver and hence is usable by any form of data hardware; for example a VDU, PC or simply a printer. The radio transceiver itself would be responsible for managing the protocol and the data link in much the same way as external packet modems do in current radio data applications.

Paging is a unidirectional telecommunications facility that has proved to be extremely successful in recent years, especially with the advent of alpha numeric pagers that are capable of receiving textual messages. In a major emergency it may be desirable to send a textual message to one or more radio units that does not necessarily require an immediate reply. Hence it would be useful if the smart transceiver were also an alpha numeric pager that produced an audible alert tone when called and display the received message on a small screen. This is a function that could easily be achieved by the control circuitry that manages the transceiver. There are many formats of pager signalling [41] but in this case the most appropriate signalling format would be to use the same packet format as the data terminal also offered by the transceiver.

As it could not be guaranteed that the radio operator was physically present to receive the paged message immediately, it would be possible to enable the smart transceiver to re transmit the paged message for reception by an actual alpha numeric pager that is in the near locality and is worn by the radio operator. This would ensure an efficient delivery of the message. One could even alert the sending station if an acknowledgement button is not pressed within a pre set time period.

All of the above services, selective calling, data transmission and paging, all imply that the smart transceiver would have a unique address so that it may be individually identified. This unique address would be programmed into the control system when the transceiver is first programmed for use by a smart card. This address would then have associated with it a set of extensions that would indicate whether the received signal was a selective call, intended for the data port, a paged message for the alpha numeric display or data intended for the control systems in order to adjust some of the units operational parameters. The address extensions would also be used to separate voice and data traffic so that system users are not continually disturbed by unpleasant data traffic from the transceivers loudspeaker which should only be operational during periods of voice activity.

If all of the above features are incorporated into the smart transceiver then it is anticipated that the transceiver could be used as a replacement for any radio transceiver that is currently in use by the emergency services. The transceiver would be capable of operating in any of the conventional modes; as a simplex or half duplex unit, via a community repeater or as part of a trunked radio system. The unit would also be capable of full duplex operation for talkthrough facilities if furnished with the appropriate antenna filtering.

In practice there are likely to be several versions of the smart transceiver. Firstly it would be desirable to have the transceiver available in three physical formats; hand held unit (portable), vehicle mounted unit (mobile), and a fixed unit (base station). In practice there will be little difference between the hardware in the three variants; the only difference being in the size of the power supply (or battery) and the output power of the final transmitter stage. The emergency services tend to use three separate parts of the radio spectrum; the low VHF region around 75MHz, the high VHF region around 150MHz and the UHF region around 450MHz. All told this is likely to lead to nine versions of the smart transceiver, however, once one has chosen the region of the spectrum within which one is operating then it would be fair to assume that the frequency agility of the transceiver is sufficient to cover that whole region of the spectrum.

The smart transceiver, as proposed, contains a large amount of hardware. One has the components of a modern frequency agile radio transceiver, a radio data modem and a sophisticated digital control system. In order to achieve a reasonable physical size for the transceiver, especially the portable models, one would have to make use of the very large scale integration (VLSI) technologies that are available. However, these problems are not new to the telecommunications industry as much of the hardware that is required in the smart transceiver is already available in a modern mobile telephone, albeit in a slightly different form.

7.4 How The 'SMART' Transceiver Would Be Used In Temporary Communications Networks

Although the use of a common radio transceiver would greatly benefit the emergency services in everyday operations and maintenance, the primary advantage is appreciated when one comes to construct temporary communications networks at a major emergency. Even though each radio transceiver may be programmed to operate in a different manner for routine usage, all radio transceivers at the location of a major incident can be reprogrammed to operate in the same manner by simply inserting another smart card before switching on the unit. All transceivers will then be operating on a common temporary network or one of the several temporary networks that may exist at the scene of a major incident.

One is now able to construct any temporary network provided that it is within the capabilities of the smart transceiver. There are several types of communication network that may be constructed.

If the traffic volume is likely to be low then the most suitable network might be one based around simplex radio channels allowing direct mobile to mobile communication on a mutually agreed channel. If the terrain does not allow direct communication then it would be possible to have one smart transceiver programmed as a local community repeater [42].

In a situation where the temporary network traffic is likely to be relatively high one might consider a trunked radio network as the most suitable based around one or two centrally located trunking base stations. This type of network, although efficient in its spectrum usage, does require a large hardware overhead in the trunking base station which, in this situation, would have to be a temporary resource located in the emergency ground. The trunking base station could be constructed from several smart transceivers, operating in talkthrough mode, that were not necessarily physically connected to each other; it would be possible for all routing information to be communicated between the transceivers on a mutually agreed data frequency.

As trunked networks require a large hardware overhead, in the form of a multi channel base station, one might consider self trunking as an alternative with a system that would operate in a similar way to the newly emerging Digital Short Range Radio (DSRR [43]). In this scenario the radio wishing to make a call scans the available traffic channels to find a clear one and then indicates to the radio being called which traffic channel to move to on a common control channel. Both radio transceivers then move to the traffic channel for the duration of the call. When the call terminates the traffic channel is freed and both transceivers return to the common control channel to await a further call unless they initiate one themselves first. Although this requires a larger processing overhead in each radio transceiver many benefits are gained. A self trunked network would be much quicker to establish simply requiring each smart transceiver to be reprogrammed, one would not have to set up a temporary trunking base station that may well have to be moved as the emergency progresses. A limitation to a self trunked system is that one is limited to the direct communication range between transceivers unless the principle is carefully extended to allow intermediate transceivers to become temporary repeaters for the duration of the call.

One could extend the principles of trunked systems further and progress to a temporary cellular radio network for use within the emergency ground. It would be possible to create a temporary network that has good coverage and is capable of penetrating local ‘radio shadows’ with careful siting of cellular base stations. However, such a network would require a large overhead in terms of base station hardware, inter base station communication, setting up time and channel requirements. Such a network would also require complex software to be written for the smart transceiver, especially those that would be used to create the cellular base stations. Such a temporary might only be appropriate for incidents that cover a wide geographical area and are likely to persist for a relatively long period of time.

If a data only temporary communications network is required then one may consider other network configurations as there is no need for direct real time connections for voice traffic. One could develop a packet radio network that uses intermediate radio transceiver to re transmit packets of data in order to extend communications range, a process referred to as digipeating. One could create a dynamic data network where each smart transceiver could 'learn' which are the adjacent units with which it can communicate so that it may predict the optimum route for data passing. Such a network would not necessarily require planning, each transceiver would simply be reprogrammed to operate in this manner and then the network would 'build' itself. At a large scale major emergency there may be a requirement for both voice and data networks so, with appropriate frequency management, both could be set up. All would be based around the smart transceiver, the difference would merely be in the way in which they have been programmed.

7.5 Future Developments

The smart transceiver proposed here is essentially an analogue communications unit being based around an FM radio transceiver. This has been proposed in order to be compatible with the radio systems that are currently in use by the emergency services so that the smart transceiver could be used as a replacement for the radio equipment in current use. However, it is likely that analogue communications systems might exist in some environments for a further significant period, thus development may well be profitable.

In the long term it is highly likely that all forms of radio communication will move to an all digital format. This has already begun within the public communications sector with the second generation of cellular telephones and DSRR as examples. Within the emergency communications sector in Western Europe development is well under way with a standard digital trunked radio format (TETRA). Consequently the smart transceiver would also have to become an all digital device. However, this would not mean a change in the concept or the facilities that are offered by the smart transceiver, simply a redevelopment of the radio hardware.

CHAPTER 8

SUGGESTIONS FOR FURTHER WORK

As a consequence of major emergencies that happened in the latter part of the 1980s in both the United Kingdom and abroad there has been much discussion over the past few years on the subject of emergency planning, especially the provision for emergency communications when dealing with these incidents and how to ensure that they are effective.

More recently in the United Kingdom there has been a shift in local authority responsibilities away from simple wartime civil defence to both peacetime and wartime emergency planning. This too has ensured that emergency communications have been considered more stringently.

There are those that now believe, with the advent of new technologies, that this topic is now planned and provisioned for, but these studies believe that there is still much scope for the development of emergency communications networks; both fixed and temporary, and how they cope with major incidents. This work has answered a most important problem, why emergency communications networks fail in major emergencies; it has suggested that the solution may well be found in temporary networks.

It is believed that the failure criteria identified in this work and the potential solutions should be applied to all of the new potential emergency communications networks. To that the end the following work is suggested as a suitable continuation to that undertaken here.

8.1 TETRA

As this work was being undertaken the Public Safety Radio Communications Project was convened by the Home Office PAGIT Communications Group to look into the future of emergency communications within the United Kingdom. It has become apparent that the way forward across Europe is for emergency communications in the retained and maybe voluntary services to move towards using the TETRA standard for radio communications. This especially is the case as it has been arranged for a common frequency band to be available across much of Europe making equipment more universal that can be sourced from many suppliers. More importantly, if all the services are using similar equipment the likelihood for interoperability will be greater. From this a specification has been drawn up and at least two companies are conducting field trials with TETRA systems aimed at the emergency services market.

TETRA is a generic standard that is aimed at replacing conventional analogue Private Mobile Radio (PMR) systems, particularly those that operate on analogue trunked networks with the initial customer base intended to be large users such as the emergency services and public transport systems, so as to cover the cost of the network infrastructure. Further valuable work would be to investigate the newly emerging TETRA systems to ensure that they do indeed meet the criteria for emergency communications systems, what has been dubbed by the market place as Public Safety Radio Systems.

More specifically applied to the work presented here there is scope for a rigorous investigation of the TETRA standard to see how it is likely to cope under the five failure criteria identified here. Again, it is believed that there will be instances when TETRA radio systems are unable to cope with the communications requirements of a major emergency and the units themselves might be required to participate in a temporary network, this possibility should be investigated.

8.1.1 Application of The Smart Transceiver Concept in TETRA

As discussed earlier the primary requirement in emergency communications is to provide a voice network as this is the natural means by which humans handle immediate communications. Given that the TETRA specification relies upon digital transmission modes the current developments in TETRA transceivers are to produce combined voice and data terminals, a concept that is approaching that of the smart radio transceiver proposed in this work.

It is felt that there would be merit in investigating how one could actually bring this concept to fruition for a TETRA radio transceiver. The use of smart card programming is a concept that can be copied from the public networks so that at switch on the transceiver is programmed to operate on the correct network. The facility of over the air reprogramming could be achieved and would be most useful to block a stolen or incorrectly used transceiver. Data communications are available implicitly in the transceiver side by side with voice communications. The creation of user acknowledged paging is merely an extension of data communications.

As it is intended that all of the emergency services will be using transceivers operating to the same standards within a set frequency band then the smart transceiver is a concept that can be achieved. A radio transceiver can be a general unit usable by any service which only becomes dedicated to one service when the smart card is inserted for programming. This enable swift repair by substitution and the lending of equipment to occur, particularly in response to major emergencies. An intention of the CAIRO scheme is directly replicated here.

8.1.2 Use of TETRA Transceivers In Local Networks

It has already been discussed that more recently the TETRA specification has been modified to allow back to back communication directly between mobile transceivers, a facility that is most useful and required for emergency ground temporary communications networks that have been proposed in this work.

There is scope to investigate how well TETRA transceivers perform in such networks and to see how they might be reprogrammed to operate in this mode with all users being able to monitor traffic that is passed on what is effectively an open voice network. It might be worth considering how this could be combined with the reprogramming of a radio transceiver by smart card so that users can simply participate in such a network by switching card. A useful facility here might be that when transmitting a unit also declares its identification so that all recipients may see the identity of the sender on their transceivers' screen.

An extension to this idea is to investigate how a TETRA transceiver may participate in a local network set up through a single repeater station used to extend communications range over an emergency ground, one would have to consider how the signalling protocol might be used for this facility to be used as it is merely an extension of the back to back facility.

8.1.3 Using a Single TETRA Transceiver As A Repeater

Another area of work would be to investigate the construction of radio relay stations from a single TETRA transceiver. This would be required to construct a temporary communications network over an emergency ground that uses a single repeater station to increase mobile to mobile communication range, as suggested above.

As TETRA uses a combination of TDMA and FDMA (4 time slots/frequency channel) it would not be necessary to have simultaneous transmission and reception, in fact impossible given that the unit it would be communicated with will also be alternately transmitting and receiving. This fact can greatly reduce the filtering hardware and size of a radio relay station, making it a truly mobile, temporary resource. This can sensibly mean that such a repeater can be constructed from a single radio transceiver that is reprogrammed to operate in this mode independent of any fixed network resource. If a TETRA transceiver has the flexibility of the proposed smart radio transceiver then this reprogramming could simply men the insertion of a card much like the mobile users of the repeater would do. In practical terms, when the need for a temporary repeater is identified an ordinary mobile radio installed into a vehicle can be driven to a suitable local high point and configured to operate as a repeater very quickly.

An alternative type of temporary repeater might be used to provide communication between an emergency ground that is out of range of the existing network and the existing network itself. One way of solving this has been the suggested use of a cell enhancer although that does have problems associated with it. An alternative approach might well be to use a TETRA transceiver itself as the radio relay station although the hardware here will be a little more difficult than that in the above proposed solution. This would deserve further detailed study.

It is quite likely that the repeater will have to simultaneously transmit and receive in a true duplex mode as opposed to a 'ping pong' duplex mode. This being necessary so that the synchronisation of the time slots remains intact to allow time for PA ramping and linearisation. That being the case it is still possible that the hardware could be constructed from a single radio transceiver but not a standard mobile. Within the TETRA specification true duplex transceivers are proposed for base station and other specialist use, it would be a transceiver such as this required for this use. Associated with this unit would be the increased use of filtering hardware, much in the same way as the conventional analogue repeater described earlier.

8.2 Public verses Private Networks

More recently in the emergency communications field there has been discussion as to whether more use might not be made of public communications networks rather than going to the expense of developing dedicated private networks [44], such an approach might be more cost effective. It might be argued that within the United Kingdom the emergency services are already moving towards using public networks. Many services make use of paging networks and mobile telephone networks in addition their own networks, particularly now that GSM mobile telephones offer a greater level of security. However, it is proposed that the new national TETRA network be provide by a network operator and the emergency services rent its use, although they will be the only users to start with, this can be argued to be a pseudo public network.

It is suggested therefore that there might be suitable further work in investigating the public networks that are available and about to become available to see how they might cope with respect to the five failure criteria identified in this work. Although public networks have a greater dependency on fixed resources investing in their use may well be advantages if in addition to dedicated networks thus offering a diversity of communications channels, a solution offered by Patterson [26]. It is worth suggesting two specific examples of public networks that might well be of use to the emergency services when responding to a major emergency.

8.2.1 The ERMES Paging Network

Paging networks are unidirectional in their message transfer and therefore cannot be used to replace emergency communications networks. However pagers are lightweight portable devices and the networks they rely on necessarily offer wide area coverage. In a major emergency there might well be benefit in using such a public network to pass messages to mobile units, either individually or as a general broadcast, thus removing the load from the existing communications network and allowing it to be used for traffic incoming from the emergency ground.

The ERMES network recently developed offers data transfer at greater rates than the traditional POCSAG networks and the maximum length of a message is larger too. If the emergency services could negotiate with a network provider that their traffic could get priority transfer during a major emergency valuable use could be made of such a system. It is felt that this is worth investigating along with the development of paging terminals suited to the needs of the emergency services incorporating facilities such as message printing and voice synthesis of a message for mobile users.

8.2.2 Data Via Broadcast Systems

The VHF FM network in much of Western Europe now offers the Radio Data System (RDS) which gives station name, alternate frequencies, alert of traffic information and other such data streams. A little known facility of the RDS scheme is the ability to flag emergency traffic for public warnings and even carry short emergency messages in the data stream [45], currently only one European country is considering using this facility.

As broadcast signals necessarily cover wide areas it may well be worth investigating if this facility could be used by the emergency services for passing emergency services data in much the same way a paging network could be used. With the advent of Digital Audio Broadcasting (DAB) which also carries such data facilities, but at a higher data rate, this too may well warrant investigation.

This chapter has shown that even though these investigations have completed their original goals, discovering why emergency communications networks fail and proposing solutions, the emergency communications or public safety radio field is never stagnant and new schemes will always warrant investigation to see how they might perform and aid communications in response to a major emergency.

CHAPTER 9

CONCLUSIONS

This thesis has encompassed a comprehensive study of the special communications needs that exist during a major emergency.

The starting point for this work was the large number of major emergencies that occurred in the United Kingdom and other parts of the world during the latter half of the decade of the 1980s, and the general belief that emergency communications systems tend to fail when responding to these incidents.

The direct interest in this field of work was fuelled by the author's own experiences in training to handle emergency communications through the UK voluntary organisation RAYNET, and more particularly with the direct involvement with further developments within the CAIRO scheme. The main philosophy behind the CAIRO scheme is that communications equipment should be universal and interchangeable to enable the quick establishment of communications networks and swift repair by immediate substitution of failed network resources. As part of this work some further developments to the CAIRO scheme have taken place and these have been fully documented. This philosophy has been extended throughout all of this research work.

The initial phase of the main investigation detailed here was a comprehensive study of cases where emergency communications networks have failed when responding to major emergencies. This involved the study of scenarios that occurred in real incidents both in the UK and from around the world. The aim of this study was an attempt to identify if any common factors could be found in the network failures that have occurred in this wide variety of incidents. If common factors could be identified then a possible solution or solutions to network failures might be sort.

It is believed that an investigation of this nature has never been carried out prior to this as no evidence could be found. From this study it is indeed believed that there are in fact five common factors involved in the failure of emergency communications networks and any particular failure might be due to any one, or combination of these factors. It is interesting to note that the emerging emergency communications systems were also considered in this investigation and evidence of similar vulnerabilities was found.

Following the results from above the next stage was to investigate communications networks to see if there might be a solution to network failures. Initially the communications systems that are currently available were investigated with respect to each of the five failure modes to asses their performance and see how they might be used to solve the problems identified above. The proposed new emergency communications systems were considered in this study too. To add validity to this argument, examples of tested and installed systems were given as examples of these currently available networks.

From the above study the next step was to theorise how one might use a combination of the facilities available to develop an emergency communications network that was tolerant to the failure modes previously identified. Three solutions were suggested; to have a diversity of communications means and use the systems that survive the effects of the major emergency (direct or indirect), to install redundant duplicate systems and, probably the most exciting, to use temporary communications networks installed specifically to fill the failed requirements of the existing communications networks.

This investigation reached the conclusion that to develop an emergency communications network that would not fail in a major emergency was very difficult if not near impossible and would be very uneconomic, primarily because one cannot predict the nature of all major emergencies and what their communications requirements might be. Hence the belief that the way forward was to develop schemes for the implementation of temporary communications networks in direct response to the communications need of the major emergency. To justify this it was suggested how such temporary networks might have relieved the network failures studied at the beginning of this investigation.

Having reached the above the conclusion the subsequent section of work was to investigate the type of temporary communications networks one might set up, it's topology, resource and equipment requirements and speed of installation. From the examples studied earlier it is felt that often the communications requirement was for a fairly low capacity system so long as it could be relied upon to get a message to its required destination. This too was found to be the case for communications within the emergency ground, the requirement low in capacity provided it offered the inter service communication. These systems were often simple in their construction but were of great benefit due to them being independent of the existing network resources.

An interesting point to note here is that in the vast majority of cases a real time voice communications network is the most apt as it is the natural form of human communication, especially in the field, and requires the minimum of manual dexterity in conditions that might be harsh.

Following these studies and the above conclusion this work then considered two engineering facilities that may well be of use in establishing temporary communications networks.

The first of these facilities was the further development of an automatic radio relay system or repeater. Such a device receives and re transmits radio signals from an advantageous point to improve the communication range between two mobile terminals or a mobile terminal and fixed point. The particular work detailed here is the development of a control mechanism to manage the cross coupling of the receiver and transmitter. This system was developed using the philosophy of the CAIRO scheme and satisfactorily demonstrated that it is capable of operating a radio relay scheme independent of human intervention proving to be most reliable over a period of years. Such a device, fixed or temporary, would be most useful in establishing temporary communications over a large emergency ground. The nature of its modular construction adhering to laid down standards allows swift repair or modification by substitution of what could be a very critical resource.

The second engineering facility considered was a suggested specification for what has been dubbed the 'smart' radio transceiver. This is a device that was proposed as a ubiquitous radio transceiver usable by any of the emergency services but programmed to the needs of the particular using service. It was proposed that such a device could be reprogrammed easily, perhaps by smart card, by the user. It would be the data stored on this card that would identify the user and the communications network upon which the radio would operate. The transceiver would offer mobile data and voice facilities.

When responding to a major emergency the general transceiver could then be used by the most appropriate user on the most appropriate network or reprogrammed to operate as part of a temporary network set up in response to the emergency. Such reprogramming would then enable the transceiver to become a network resource such as a temporary repeater in addition to being simply a user terminal.

It is likely that such a device could now be realised with advent of the TETRA scheme that is to be used by the emergency services and this work proposes that this be done.

Finally, as is the case with many research projects linked with current engineering problems, the subject is not closed with the completion of this work. This report details future work that can be undertaken in the field of emergency communications networks, particularly with respect to the emerging technologies that are proposed for installation at the beginning of the next century.

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APPENDIX 1

This appendix contains a so far unpublished short paper that is referred to in chapter 6, Radio Relay Stations.

AN OPTICALLY ISOLATED AUDIO INPUT FOR RADIO TRANSCEIVERS

M. A. Higlett

This letter reports the success of an alternative method of providing an isolated audio input signal to a radio transceiver using an opto isolator as opposed to the more traditional transformer. The method of operation of the circuit is explained and examples of its uses are given. Those given highlight the main advantage that this alternative isolation method provides, that of digital control and selection of the audio coupling in use. Although this principle is described with reference to radio transceivers, as this was the environment within which it was developed, this method of audio coupling is capable of being used in a wide range of applications.

Introduction

Voice radio transceivers often have a microphone input consisting of a pair of isolated conductors, even though one of the two conductors may be referred to system ground within the transceiver itself. Isolated conductors are used for this low level signal in order to prevent any degradation of audio quality or RF instability occurring due to detrimental earth loops; especially if the microphone is situated more than a few metres from the radio transceiver using a longer connection line between the two. In some communications applications the user may wish to inject an audio signal into the radio transceiver that is not derived directly from a microphone; for example, it may be a signal from a radio data modem (i.e. a non human source) or a voice signal at a higher level derived from a line source. Any suitable attenuation of the alternative signal can be easily achieved in order to make it equivalent to a microphone level but before it is injected into the radio transceiver the signal must first pass through some form of isolation in order to be presented as an isolated pair of conductors. Classically this is achieved by using a small communications signal transformer.

The electret condenser microphone is now commonly found on many voice radio transceivers due to its small physical size and good audio characteristics. However, such microphone elements require a DC bias to be present on their terminals in order to power the FET amplifier that is contained within the element. This amplifier is incorporated because the output of the actual condenser element within the capsule is of an extremely low level and requires a high impedance load. As a result of the widespread use of the electret condenser microphone element it is now common place for radio transceivers to present a DC bias across their two microphone terminals, this being known as phantom powering. This DC bias is current limited by a series resistor so that no harm is caused to any other microphone element that may be used, such as the more traditional dynamic element.

Since this DC bias is present on the microphone line, there is no reason why it should not be used for powering any other active device that may be supplying an audio input to the radio transceiver, which of course includes some form of active audio coupling system as opposed to a microphone element.

The Opto Isolator For Audio Coupling

An alternative method of providing an isolated audio input to a radio transceiver can be to use an opto isolator as opposed to a transformer. One must use an opto isolator that has a linear photo-detector as its output so that a linear coupling can be achieved between input and output. One such possible configuration is given in figure A.1.

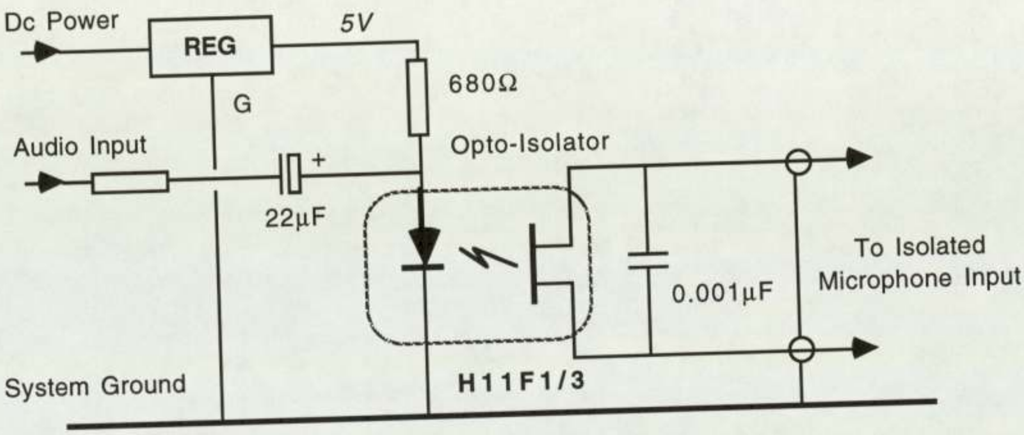

Figure A.1 - The Opto Isolator Audio Coupling

The opto isolator used in the circuit shown is an H11F1 or an H11F3, the two being electrically similar except with respect to their isolation voltages between the emitter and the detector. The H11F1 offers a peak isolation voltage of 2500V as opposed to that of the H11F3 at 1500V. The device has a gallium arsenide infrared emitting diode which is optically coupled to a symmetrical bilateral silicon photo detector which behaves as an electrically isolated FET [A.1]. As a consequence, when biased by the microphone input of a radio transceiver, the output of the opto isolator behaves exactly like the FET output of an electrically isolated electret condenser microphone. The principle of operation of the circuit is quite simple; the emitter has a standing DC bias on it which is provided by means of a series resistor from a steady 5V supply derived from a three terminal regulator and its associated passive components (denoted as REG). The illumination of the emitter is then intensity modulated by an audio input signal which is coupled to the emitter's anode by means of a series resistor. This modulation then causes an audio output signal to be present across the terminals of the detecting FET in much the same way as speech would appear across the terminals of an electret condenser microphone. The circuit also possesses attenuation, thus providing suitable coupling from a line level signal to the isolated microphone input of a radio transceiver. The level of attenuation is controlled by the value of the series resistor between the audio input terminal and the anode of the emitter. The junction impedance of the emitter remains constant due to the standing DC bias across it. The values shown provide an isolated attenuation between a line level signal at 0dBm and the microphone input of a radio transceiver (at approximately -45dBm).

The circuit possesses several advantages over that which may be achieved by means of a small isolation transformer, the first being that it is physically more compact.

Control of The Through Audio Path

Since this method of audio coupling is active, it also possesses a degree of control that is achieved by switching the DC power to the circuit. When DC power is denied there is no standing bias on the emitter and hence it does not illuminate leading to a denial of the through audio path. This offers a very simple method of switching the through audio path. However, there is a better method of switching the circuit making it directly compatible with TTL logic control.

If the cathode of the emitter is connected to the open collector output of an O/C TTL gate, rather than directly to 0V, as shown in figure A.2, the through audio path is only enabled when the output of the gate is in its low state. The capacitor is included between the emitter's cathode and 0V so as to provide a low impedance path to 0V for the superimposed audio signal. Although this capacitor does slow the switching time to around 20ms, in this application the delays are considered negligible. The control of the through audio path is now TTL compatible enabling it to be controlled by any form of digital control circuitry.

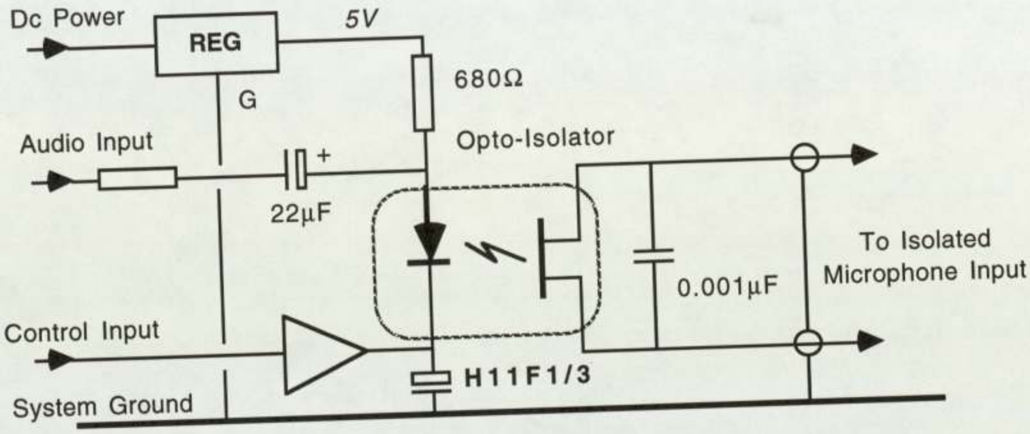

Figure A.2 - The Controlled Opto Isolator Audio Coupling

Selection of Various Audio Inputs (Creating An Audio Bus)

When the opto isolator's emitter is switched off the FET output stage has a very high resistance; >300MOhm. Hence, the outputs of several opto isolators may be connected in parallel with the inputs of each isolator being fed from a different signal source. If each opto isolator circuit was controlled as described above then it would be possible to select which audio input from many, one wishes to supply to the microphone input of a radio transceiver. This leads to the notion of the microphone input to the radio transceiver becoming a bus line with several drivers connected to it with any one enabled at a moment in time. The range of input signals to the collection of opto isolator circuits could be very wide including items such as radio data modems, voice signals, pre-recorded announcements and alert tones. This principle of signal selection has already been demonstrated to work [A.2].

One can extend this idea further and have more than one opto isolator for coupling any one signal but with each coupling offering a different level of attenuation. If this were to be used not only could one select which input signal of many was to be supplied to the radio transceiver but one would also have some control on the level at which the signal was supplied. An arrangement could be used whereby two opto isolators provided a 'quiet' and 'medium' level of coupling of a particular signal and, if the two opto isolator outputs are connected in the correct way so as to be in phase, one could achieve a 'loud' level of coupling by enabling both opto isolators simultaneously. However, it should be stated that one should not enable more than two opto isolators at once so as not to cause a detrimental loading on the DC bias provided by the radio transceiver.

An example of signal selection might be when one wishes to use the same radio transceiver for both voice and data communication. Both the output of the data modem and the voice signal could pass to the radio transceiver via an opto isolator circuit which is switched so that it is only enabled when information is to be passed; i.e. when the modem has data to pass or the manning operator has information to communicate. The switching of the two opto isolator paths could be controlled by some form of digital circuit assigning priority to the two radio channel users, the manning operator and the modem. In order for this to operate correctly one would have to use a data transfer mode that does require a permanently open channel and includes error correction should corruption due to voice activity occur. One such suitable transfer mode is the AX25 protocol otherwise known as 'packet radio'. In this instance, one could argue that voice activity should have priority over data activity as the data protocol does not require real time connections unlike voice operations.

Conclusion

This letter offers an alternative method of providing an isolated microphone level input to a radio transceiver that has advantages over the more classical solution of using a small signal transformer. The method uses an opto isolator that has linear characteristics and makes use of the DC bias that is present on the microphone input of many radio transceivers anticipating the use of electret condenser microphones. It has been shown that the opto isolator method of signal coupling is more flexible by offering controllability and selectability of input signals to a radio transceiver by means of digital control signals. An example of how this control may be used has been described.

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