International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-2 Issue-3, February 2013

# Promising Communication Technologies for Emergency and Safety Systems

**Anwar M. Mousa**

***Abstract*—this article discusses the uses of promising modern communication technologies for emergency and safety systems focusing on cognitive radio technologies and their roles in effective spectrum use. Given that only 10% to 30% of licensed spectrum is occupied in a specific time and locations, the remaining unused spectrum constitutes a huge room for increasing bandwidth and hence the number of served users in emergency events. Based on cognitive radio and sensed spectrum holes, the paper developed new approximated linear relations between the total number of served users in emergency situations as a function of total available bandwidth. Results show that increasing the number of channels per cell, as a result of sensed spectrum holes, yields a significant increase in cell capacity and the number of served users. The paper begins with highlighting the impact of current andpromising communications technologies on strengthening disaster awareness and mitigation.***

***Keywords*—emergency communications, trunking, cognitive networks, spectrum holes, system capacity.**

## I. INTRODUCTION

It is an established fact that modern communications technologies are powerful and indispensable tools in emergency situations for disaster awareness and mitigation. Trunking systems, cellular, and wireless networks but also VSAT, remote sensing and global positioning systems are current technologies for emergency and safety systems. However, cognitive radio networks are chosen as the preferred technologies due to its efficient unused spectrum sensing and management and its great adaptability to the changing conditions in emergency situations. Nano-sensors and nano-enabled sensors, VANET communications, high-altitude platforms and direct device-to-device communication are complementary promising technologies used in tracking approaching hazards, alerting authorities and warning affected populations. The main goal for safety and emergency networks is to ensure that voice, data and video services are available under some strict quality and coverage criteria. Besides, interworking among different communications systems is mandatory in emergency situations since the emergency services normally have different communication architectures and technologies.

This paper discuses the uses of modern promising communication technologies for emergency and safety systems and is organized as follows: Section 2 highlights the current and promising technologies for emergency and safety systems. It introduces trunking systems and wireless sensor networks mainly used in disaster preparedness and warning. It presents in brief cognitive radio network' architectures and main modern wireless and cellular networks used in emergency situations. Section 2 ends with summarizing complementary promising communication technologies that strengthen disaster awareness and mitigation. Section 3, constituting the main part of the research, discusses the impact of cognitive radio and spectrum sensing on trunking systems capacity. Based on Erlang formula and trunking theory, relations between the total number of served users in emergency situations and available bandwidth, increased with sensed unused spectrum (spectrum holes), will be investigated. Finally, section 4 concludes the article.

**Manuscript published on 30 February 2013.**
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## II. COMMUNICATION TECHNOLOGIES FOR EMERGENCY AND SAFETY SYSTEMS

Below is a basic description of the current and promising systems available for use in emergency situations.

### *A. Trunking*

In communications systems, trunking is the grouping of multiple user circuits into a single channel. A 'trunk' is a communication channel between two or more points, typically between the telephone company central office and users' circuits. Trunking increases the capacity of the radio system by dynamically managing the use of a radio channel. The trunking user equipments can be partitioned into 'talk groups' so that users with similar communication requirements; such as civil defense teams, hospital emergency teams, police …etc, can communicate with each other. Following are two up-to-date examples for trunking systems:

**1. TETRA (Terrestrial Trunked Radio)**

TETRA [1] is a set of standards for a common mobile radio communications infrastructure throughout Europe, developed by the European Telecommunications Standardization Institute (ETSI) [2]. It is dedicated for public safety groups such as police, fire and health departments, utility companies, and other organizations that require robust voice and data communications services. Manufactured with solid encryption technologies to ensure security and confidentiality of communications, TETRA integrates features from several different technological areas including mobile radio, digital cellular telephones, paging, and mobile wireless data. The products of TETRA are offered with the ability of faster data transfer rates than seen before in trunking mobile communications. The TETRA channel bandwidth is 25KHz where it uses time division multiple access (TDMA) technology to divide each carrier into 4 time-slots to accommodate 4 users. The frequency bands for emergency systems in Europe was agreed to be 380-385MHz and 390-395MHz [3].

Although TETRA was designed primarily as an emergency communications system, it is now being considered for wide areas of applications. The general features of TETRA systems are:

- Integrated voice and data communications in one handset
- Very secure voice and data communications with robust encryption.
- Potential of direct mode implementation where the user equipments can operate together without the need for a network infrastructure.
- Very resistant to failure, as the system was designed for public safety use.
- Possibility of relay mode where a single mobile with a connection to the network can act as a relay for other mobiles thereby extending coverage or range.

**2. TEDS**

TETRA Enhanced Data Service (TEDS), generally referred to as TETRA release 2[4], is mainly developed for the emergency services. It provides higher speed data service using up to 6 radio channels of 25 KHz combined for one data connection; data rates of 30 - 400 kbps could be possible, depending on the chosen number of radio channels and the distance from the base station.

**3. TAPS**

TETRA Advanced Packet Service (TAPS) is an extension of the TETRA standard, based partly on the GSM standard to facilitate the interworking with GSM and UMTS services and to provide higher speed data service[5]. It is has 200 kHz radio channels bandwidth and supports data communications only.

**4. iDEN**

iDEN (integrated Enhanced Digital Network) [6]provides its users a trunked radioin addition tocellular-like telephone services. The iDEN handset looks similar to cellular handset; uses SIM cards and GSM signaling for call set-up and mobility management. The iDEN technology supports multiple services: digital wireless phone, short message services, and Internet access. It is spectrally efficient radio technology that utilizes TDMA techniques to accommodate up to 6 TDMA time slots (traffic channels) in one 25 KHz radio channel.

**5. WIDENS**

WIDENS is a type of network that could be quickly deployed in emergency areas where communication infrastructures are subject to be destroyed. It is also straightforward to deploy in the field with no need to install any specific equipment such as aerials Primarily developed by the IST-funded project WIDENS[7], its standardization activities is being carried out within project MESA [8], a transatlantic initiative for future public safety broadband communication systems. WIDENS offers high throughput capable of exchanging large amounts of sensor data such as images for telemedicine applications, or to use video-surveillance. Besides, WIDENS system is flexible; it could be used as a standalone system to provide communications in remote regions where it needs to be connected to backbone network via satellite or airborne platforms.

### *B. Sensor Networks*

Wireless sensor networks (WSNs) [9] is mainly used in disaster preparedness and warning. WSNs are collections of micro-sized sensors powered by low-energy batteries and equipped with micro-processors, small memory and radio transceivers. Sensors may measure, vehicle speed ,distance and direction, humidity, temperature, wind speed, water level, chemicals, light, vibrations, seismic data, acoustic data, strain, torque, load, pressure, fire, and so on. Before a disaster, two preparatory steps are outlined below.

- Sensors employed in the field transmit local environmental information at regular intervals to an emergency operation center comprising a data processing center. For example, seismic sensors transmit earthquake related information that can be used for warnings about earthquakes and/or tsunamis. The communications can be done via wire-line, wireless, or satellite transmission. Figure 1 illustrates communications from sensors to the emergency operation center. The emergency operations center, which is assumed to be monitored by humans 24 hours a day, analyzes the sensor data and makes a decision whether or not disaster warnings should be issued.
- If the decision is to issue warnings, then the warning information can reach the individuals in the disaster area via wireless or wire-line transmission, or by the use of visual/sound alarms. For rural and distant disaster area, satellite transmission is used. Figure 1also illustrates communications from the emergency operation center to individuals in disaster related areas. The main principle is to have sufficient lead time so that people can take measure to prevent or minimize damage. The warning could be provided in terms of a signal appropriately channeled to provide either some visual indication of the impending disaster or in audible form like sirens, provided it is sent in the proper format and then broadcast in an emergency channel. At the signal receiver end, there should be sufficient identification to differentiate the warning signal. Once identified, the receiver will then generate the required alarm.

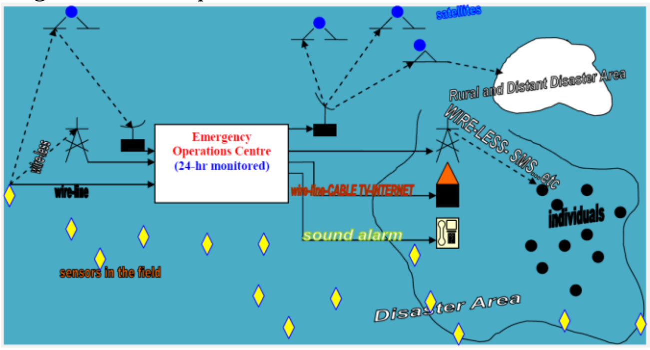


Figure 1: Data transmission from sensors to the emergency operation centre and transmission of emergency warning to individuals.

### *C. Cellular, Wireless Networks and VSAT*

The main function of emergency communications is to set up communication networks so that survivors can establish a contact or can be located by the rescue teams through common electronic devices such as mobile phones. It is expect that some or all communication infrastructure in the disaster related areas are destroyed. In the case that some base stations of cellular networks remain after the disaster, the remaining base stations can be utilized for tracking of survivors. This can possibly be done assuming the availability of a mobile phone with the person(s) affected. Here the surrounding base stations can be asked to link the mobile stations that they see and provide that information to the emergency operation centre.


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International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-2 Issue-3, February 2013

In addition, several portable radio transmission towers mounted on heavy-duty vehicles could be distributed over thedisaster area to provide overall radio coverage to the area. Each portable unit is a self contained 'network-on-wheels'. Each portable transmission tower is equipped with multi-radio interfaces: a cellular 2G BTS /3G Node B/4G e-NodeB[10]and/or a 802.11 WLAN[11] / a 802.16 mobile-WIMAX[12] access points. These can be used to set up the emergency network. However, the above strategy based on using the remaining base stations may not be applicable when all base stations are destroyed. In this case, one possibility is to use satellite communications for each survivor. For this scheme to be possible, a regular mobile phone needs to be able to communicate with a satellite. The modifications of existing systems may include having high power emergency channels available in the satellite, add-on extendable antennas for the mobile phone, and hardware/software reconfiguration in the mobile units, and so on. In the cases where adding the satellite feature to each regular mobile phone is too expensive, an alternative network architecture can be considered. The architecture consists of portable radio transmission towers mounted on heavy-duty vehicles equipped with a VSAT (Very Small Aperture Terminal) [13] transceiver that connects toa communication satellite. The VSAT transceiver could be connected toa 2/3/4G gateway through an ATM switch and a satellite modem hence provides access, via BTS/Node B antenna to mobile phones that aresatellite incapable. Besides, an ad-hoc network can be formed where connections are established among mobile phones directly. Moreover, it would be extremely helpful, if the position of the affected persons can be located. Possibility of location by Global Positioning System (GPS) [14] could be implemented by connecting a GPS enabled Mobile phone and a GPS satellite.

### *D. Cognitive radio Networks (CRNs)*

The development of cognitive radio technology has been driven by many factors. One of the major drivers has been the steady increase in the need for the radio spectrum together with improved communications and speeds. Besides, initiatives to make more effective use of the spectrum, less cost and greater communications flexibility has been required in emergency situations.

Regulatory bodies all over the world started to look at how to use spectrum more effectively as it becomes a more scarce resource.Cognitive Radio based emergency networks have different requirements compared to ordinary networks. Here are some physical layer related requirements:

- The multiple services should be supported includingreal-time voice, data message, still pictures and video. Tosupport multiple services, different constraints on QoS have to be met.
- The radio needs to be robust to combat badphysical channel conditions.
- Energy-efficiency is a concernbecause the battery life of radio devices can be a limitation for successful operations.
- The radio should be operationalin presence of jamming.

CRN architecture consists of two kinds of wireless communication systems: Primary Network (PN) and Cognitive Radio System (CRS), which are classified by their priorities on frequency bands. PS has an exclusive right to a certain spectrum band while, CRS does not have a license to operate in the desired band. There are three components in CRS: Cognitive Radio Base Station (CR-BS), Cognitive Radio Mobile Station (CR-MS) and Core Network (CN). These three basic components could compose three kinds of network architectures in the CRSs: Infrastructure, Ad-hoc and Mesh architectures, introduced as follows:

#### *1. Infrastructure Architecture*

In the Infrastructure architecture, CR-MSs communicate with each other through the CR-BS both in licensed and unlicensed spectrum bands. Communications between different cells are routed through CN. CR-BS can dynamically sense available spectrum holes around it and gather other CR-MSs' sensing results using cooperative sensing technique. The CR-MS can either access the CN or communicate with other systems under the coordination of CR-BS.

#### *2. Ad-hoc Architecture*

In ad-hoc architecture,there is no defined infrastructure. If a CR-MS recognizes that there are some other CR-MSs nearby, connectable through certain communication protocols, it can set up a link with them and thus form an ad hoc network. Exchanging spectrum hole information is achieved by a common control dedicated for this purpose. The links between nodes could be set up by different communication technology, using existing communication protocols on both licensed and unlicensed spectrum bands.

#### *3. Mesh Architecture*

Mesh architecture is a combination of Infrastructure and Ad Hoc architectures.CR-MSs can either access the CR-BS directly or using other CR-MSs as multi-hop relay nodes. Using available spectrum holes, CR-BSs can work as wireless routers and form wireless backbones.

### *E. Interworking (interoperability) among heterogeneous systems*

Interworking (interoperability) among heterogeneous communications systems is mandatory in emergency situations since the emergency services (fire, medical, police, etc) normally have different communications technologies. Besides, reconfigurable radios help to achieve more effective communications. The NGNs will require the design of a single wireless user terminal able to autonomously operate in different heterogeneous access networks. A fully reconfigurable terminal changes its communication functions depending on network and/or user demands. Moreover, this terminal will have to exploit various surrounding information such as communication with navigation and localization systems and communications with weather forecast require for emergency operations. Also, the terminal awareness will put strong emphasis on the concept of cognitive radio and cognitive algorithms for stand-alone terminal reconfigurability and interoperability. The terminal reconfiguration enables it to be connected to different radio access technologies; ranging from 2G/GERAN to 3G/UTRAN and 4G/EUTRAN in addition to 802.11x WLAN and 802.16x WMAN. Other standards are also enabled such as IS/95, EV-DO, CDMA2000...etc.

CRN can facilitate interoperability among different communication systemsin which frequency bands and/or transmission formats differ. In addition to the aforementioned three kinds of CRS accesses in subsection 3.1.3, infrastructure, ad-hoc and mesh architectures, the CR-MS can access the


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Primary Network-Base Station (PN-BS) through the licensed band, if the primary network is allowed. CR-MS will reconfigure itself and become one part of the PN. In this case, it will become a primary user on that band. Unlike other access types, CR-MS should support the medium access technology of the PN. Furthermore, PN-BS should support cognitive radio capabilities.

### *F. Complementary Promising Communications Technologies.*

In this subsection, a brief presentation of complementary promising technologies to strengthen disaster awareness and mitigation is introduced.

- ***Nanosensors and nano-enabled sensors***

Nanosensors and nano-enabled sensors have remarkable applications in safety, and national security; nanotechnology enabled mobile phones to act as intelligent sensors [15].

- ***VANET Communications***

Vehicular Ad Hoc Networks (VANET) plays an important role in safety and emergency communications such as the notifications of car accidents and bad weather conditions. Applications in VANET can be deployed by using vehicle-to-infrastructure (V2I) communications or vehicle-to-vehicle (V2V) communications.

- ***E-Healthcare Systems***

The wireless-equipped healthcare systems can remotely and continuously monitor the patients' health status in emergency situations at home and outdoor. Early detection of patients' emergency situations via wireless communications makes it possible to provide timely first-aid and access to patients' health information in a pervasive manner, thereby improving both system reliability and efficiency.

- ***High-altitude platforms (HAP)***

The most common use of HAPs [16] is for environment and weather monitoring. Several experiments are being performed by high-altitude balloons mounted with scientific equipment and used to measure environmental changes and to track weather. Another future use which is currently being tested is monitoring of a particular region for specific activities such as flood detection, seismic monitoring, remote sensing and disaster management.

- ***Direct Device-to-Device Communication***

In emergency and public safety scenarios, the possibility for direct device-to-device communication (two mobile terminals communicate directly with each other without going via the network) could be of interest where no network infrastructure is available.

## III. IMPACT OF COGNITIVE RADIO AND SPECTRUM SENSING ON NETWORK CAPACITY

This section focuses on cognitive radio technology and its role in enhancing the capacity of emergency networks as a result of bandwidth increase.

### *A. Unused Spectrum (Spectrum Holes)*

According to spectrum measurement by Victoria University from 1 MHz to 1GHz during 5 minutes snapshot in densely populated area, 70% to 90% of licensed spectrum is not used, constituting spectrum holes [17], Figure 2. A spectrum hole is defined as a frequency band that is assigned to a primary user exclusively, but is not allocated by this user at a specific time and place [18].

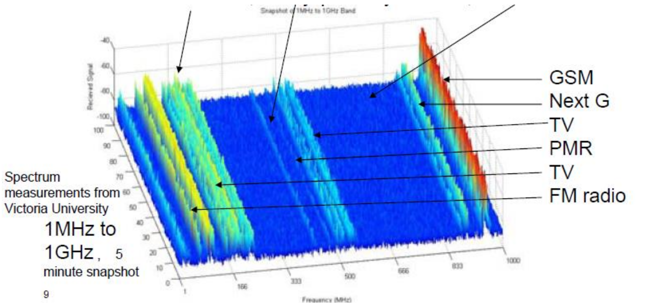


Figure 2: Spectrum Measurement from 1 MHz to 1GHz during 5 minutes snapshot in densely populated area, *source from [17]*

A spectrum hole is a synonym to white spaces where these spaces are free of local interferers; the only interference is due to ambient noise (thermal or impulsive noise). Hence, white spaces can support dynamic allocation techniques. On the other hand, black spaces are highly occupied by local interferers and hence are no proper candidates for dynamic spectrum allocation. Grey spaces come in between where these spaces are partially occupied by interferers and can partially support dynamic allocation techniques. DSM(Dynamic Spectrum Management) is proposed to enhance the spectrum utilization. Steps for DSM are as follows [19]:

- Spectrum sensing: detect the spectrum holes
- Spectrum decision: choose the best available spectrum channel
- Spectrum sharing: share the spectrum with primary users
- Spectrum mobility: leave the channel occupied and find another suitable channel for communication

### *B. Trunking Theory and Erlang Formula*

Trunking theory was developed by a Danish mathematician Agner Krarup Erlang who based his studies on the statistical nature of the arrival and the length of calls. Erlang developed the fundamentals of trunking theory while investigating how a large number of users can be serviced by a limited number of channels. Statistical behavior of users accessing the network is discussed in the assumptions of the Erlang B formula [20], Equation 1.Erlang B formula allows for the calculation of the number of channels required to offer an amount of traffic in Erlangs based on the Grade of Service (GOS). GOS, or blocking probability, is a measure of the probability that a user may not be able to access an available channel because of congestion.

$$Pr[blocking] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C}\frac{A^k}{k!}} = GOS$$

Equation 1: The Erlang B formula

where:

- GOS is the probability of blocking during the busy hour
- $C$ is the number of runked channel per cell in a cellular system.
- $A$ is amount of traffic per cell offered in Erlangs.

Based on trunking theory, cell capacity (traffic intensity in Erlangs and hence the number of served users per cell) depends on the number of trunked channels per cell which, in turn, depends on the amount of the available spectrum.Suppose the available total bandwidth for a trunking system is $2W$Hz


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International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-2 Issue-3, February 2013

($W$Hz for each direction), where $W$ is a scalar quantity in Hz, and the bandwidth of the channel is $B$Hz then the number of the overall available channels is $W/B$ channels. If the trunking system uses cluster size of $N$ cells; $N$-cell reuse factor is used, then the number of channels for each cell $C$, is given as:

$$C = W/BN$$

Equation 2: number of channels as a function of single channel bandwidth and cluster size

Now if a CRN manages to double the available bandwidth by sensing spectrum holes, from the unused 70% to 90% of licensed spectrum, then what is the expected overall gain in cell capacity or traffic intensity in Erlangs at a specific GOS? Unfortunately the answer is not so clear from Equation 1; it does not give a smooth answer for how much the network capacity (traffic intensity in Erlangs, $A$) will increase when the number of channels for each cell, $C$,is doubled for a fixed GOS!

To have a close insight at the effect of the number of trunked channels on the traffic intensity per cell, the traffic intensity, $A$ in Erlangs, is evaluated for various numbers of channels and different values of GOSs. The numerical values are plotted in graphical form in Figure 3.

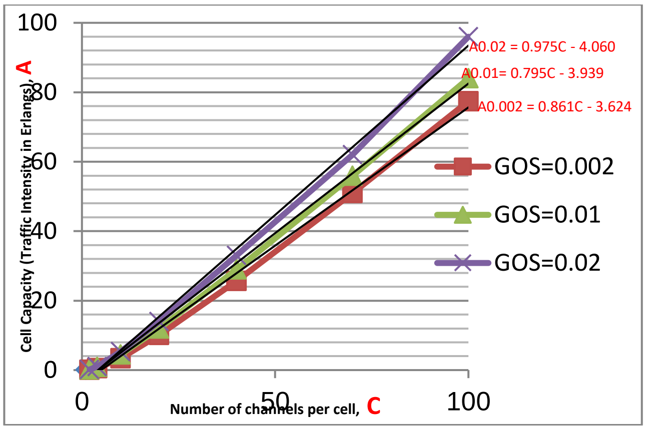


Figure 3: Traffic Intensity per cell as a function of Number of trunked channels

To investigate the amount of increase in cell capacity at various GOS's when the number of channels per cell increases, it can be seen from Figure 3 that:

- Doubling the number of channels per cell when it is small yields a large gain in terms of traffic intensity; from 5 to 10 channels, the cell capacity (traffic intensity in Erlangs) increases at an average ratio of 360%.
- Doubling the number of channels per cell when it is intermediate still yields a large gain in terms of traffic intensity; from 10 to 20 channels, the cell capacity increases at an average ratio of 280%.
- Doubling the number of channels per cell when it is large yields a significant gain in terms of traffic intensity; from 20 to 40 channels, the cell capacity increases at an average ratio of 247% and from 40 to 80 channels, the cell capacity increases at an average ratio of 234%.

This can be easily verified by Equation 3 that consists of three linear equations approximated, by interpolation, for the relation between traffic intensity, $A$, and the number of channels per cell, $C$, for various values of GOSs as shown near actual curves in Figure 3.

$$A0.02 = 0.975C - 4.060, \quad GOS = 0.02 \quad (a)$$
$$A0.01 = 0.795C - 3.939, \quad GOS = 0.01 \quad (b)$$
$$A0.002 = 0.861C - 3.624, \quad GOS = 0.002 \quad (c)$$

Equation 3: Linear equations approximated for Erlang B formula.

To find the relation between the number of served users per cell, $U$, as a function of the numbers of channels, $C$, the traffic intensity per cell is to be converted to number of served users. To do so consider the following:

The total traffic intensity per cell, $A$, equals the number of users per cell, $U$, multiplied by the average traffic generated by each user, $Au$.

$$A = UAu$$

Equation 4: The total traffic intensity per cell as a function of the number of users per cell and the average traffic generated by each user.

$Au$ equals the average number of user's calls request per hour, $\lambda$, multiplied by the average duration of a typical call in seconds, $H$.

$$Au = \lambda H$$

Equation 5: The average traffic generated by each user as a function of calls request per hour and the average duration of a typical call

Investigations[20] have indicated that in ordinary situations a residential user generates 0.02 Erlangs of traffic with an average of one call per hour and average call duration of 72 seconds (1.2 minutes), hence: $Au = \lambda H = 1*1.2/60 = 0.02$. However, in case of emergency situations, it is expected that the average number of user's calls request increases rapidly generating an average traffic of more than 0.1 Erlangs. Figure 4 shows the number of served users per cell as a function of the number of trunked channels, for GOS=0.02, for the following two cases:

- The first case represents ordinary situation with average traffic generated by each user, $Au=0.02$
- The second case represents emergency situation with average traffic generated by each user, $Au=0.1$.

Linear equations were approximated for the two cases, with their lines shown near actual curves in Figure 4, as:

$$U0.02 = 49.38C - 203.6, \quad Au=0.02 \quad (a)$$
$$U0.1 = 9.873C - 40.56, \quad Au=0.1 \quad (b)$$

Equation 6: Linear equations approximated for number of served users per cell, $U$, as a function of number of trunked channels, $C$.

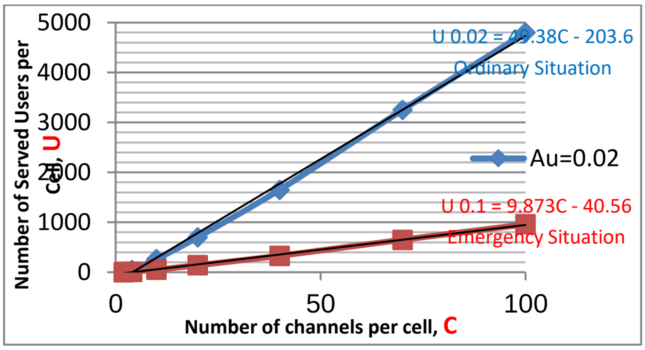


Figure 4: Number of Served Users per Cell as a function of Number of trunked channels

It is easily shown from Figure 4 that the number of served users in ordinary situations is much higher than that in emergency for same number of channels per cell. This is due to the increased request of calls by the users in emergency situations and hence increased average traffic generated by each user. In general, increasing the number of channels per cell (as a result of sensed spectrum holes) yields a significant increase in cell capacity, and hence, increase in the number of served users. Equation 6 (b) gives an approximate linear relation between the number of served users and the number of channels per cell in emergency situation.


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Given that only 10% to 30% of licensed spectrum is occupied in a specific time and locations, the remaining unused 70% to 90% spectrum constitutes a huge room for increasing bandwidth and the number of served users in a specific time and location in emergency events. For an emergency trunked cellular system, substituting the value of *C* from Equation 2 in Equation 6(b) gives an approximate linear relation between the number of served users per cell and the total available bandwidth, assuming fixed channel bandwidth *B*, and cluster size *N*, as

$$U = 9.873W/BN - 40.56$$

Equation 7: Linear equations approximated for number of served users per cell, *U*, as a function of total available bandwidth

Finally if the total number of working cells in the emergency trunked system is *K*, then the total number of served users *Ut*, is given by

$$Ut = 9.873\ KW/BN - 40.56$$

Equation 8: Linear equations approximated for the total number of served users as a function of total available bandwidth

The channel bandwidth for most of trunking emergency systems (as shown in subsection 2.1) is B=25KHz (each channel is divided into 4-6 time slots- traffic channels- using TDMA) and the total allocated bandwidth is BW=5MHz (380-385 MHz uplink and 390-395MHz downlink)

Figure 5 shows the number of served users per cell as a function of total available bandwidth for two values of cluster size *N* (*N*=7 and *N*=12). It is easily indicated that the number of served users per cell is higher at cluster size *N* =7 than at *N*=12. This is due to more clusters required to cover the service area and hence more capacity is achieved.

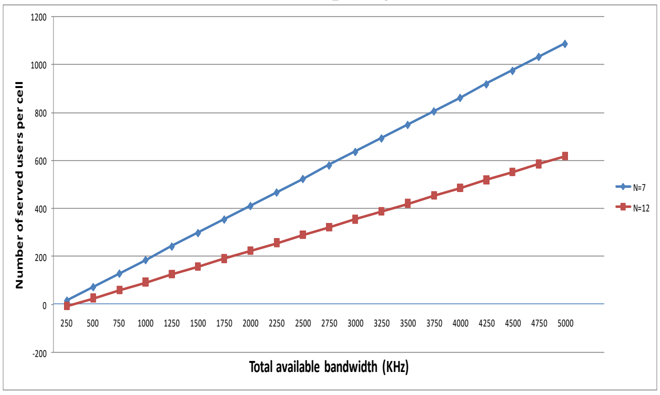


Figure 5: Number of served users per cell as a function of total available bandwidth

At the 1000 KHz and N=7, the number of served users per cell is 185. If the allocated bandwidth is doubled (2000 KHz) by sensing spectrum holes, then the number of served users per cell will be increased to 410 which represents 222% of the original value. While the number of useful resources (time slots-channel) per cell is doubled, the number of served users is 22% more than the doubled value. At the 1000 KHz and N=12 the gain is more obvious; the number of served users per cell is 91. If the allocated bandwidth is doubled (2000 KHz) by sensing spectrum holes, then the number of served users per cell will be increased to 222 which represents 244% of the original value. Hence, 44%gain. This gain is illustrated by trunking efficiency as a measure of the number of users that can be served with a particular GOS given a particular configuration of specific number of useful resources (time slots-channel). The number of served users by a system depends on the way in which useful channels are grouped. Hence, the overall system capacity is strictly altered by the allocation of spectrum and hence channels in a trunked system.

As the total bandwidth allocated for emergency systems is 5 MHz of which a part is granted for each operator, the application of cognitive radio will clearly increase the capacity of each emergency system by searching the unused spectrum at the other systems and use it at the free time.

If the 5 MHz band is equally divided between two emergency operators with 2.5 MHz each and each network, enhanced with CR, manages to sense 35% The ratio 35% percentage is chosen as an average value since not all the 70% to 90% of unused spectrum could be used by the CRN without interference in a specific time and location. The amount of sensed spectrum holes depends on the efficiency of the CRN and the applied spectrum sensing techniques. At some time and location, the bandwidth available to CRN could be more while at other time and same or other location the bandwidth available to CRN could to be much less. of the spectrum holes in the other network's band, then the expected increase in bandwidth will be about 0.875 MHz; (0,35*2.5 MHz). Adding 0.875 MHz to 2.5MHz yields 3.375 MHz and from Figure 5, 3.375 KHz serves 722users per cell at cluster size of 7. Comparing this result with only 523 users per cell at 2.5 MHz, the gain is about 38% increase in number of served users. The gain is about 40% in case of higher cluster size (N=12) where lower number users per cell are served, enjoying lower co-channel interference; the number of served users per cell is increased from 288 at 2.5MHz to 404 at 3.375 MHz.

## IV. CONCLUSION

The developed new mathematical linear relations between the total number of served users in emergency situations as a function of total available bandwidth showed that increasing the number of channels per cell, as a result of sensed spectrum holes, yields a significant increase in cell capacity and the number of served users. The gain depends on the adopted cluster size where it may reach 40% in case of higher cluster size (*N*=12) and slightly lower in case of lower cluster sizes. The amount of sensed spectrum holes depends on the efficiency of the CRN and the applied spectrum sensing techniques. The CRN used for emergency service is expected to have standby hardware capability to accommodate the increase in the number of sensed channel. If the sensed spectrum exceeds the CRN's hardware capacity then the gain could be achieved in terms of enhanced GOS (reduced blocking probability).

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