SPECTRUM MANAGEMENT IN PUBLIC AND GOVERNMENT SECURITY (P&GS) SYSTEMS; MAKING USE OF ‘QUIET’ TIMES

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ABSTRACT

The WINTSEC project, a Preparatory Action on the enhancement of the European industrial potential in the field of Security research (PASR), investigates the possibilities and functionality required for wireless interoperability for security relevant communications.

Public and Government Security (P&GS) systems have the exclusive usage of licensed spectrum to provide communications for local and state law enforcement authorities, fire and emergency services, and other critical health and safety personnel. From commercial systems point of view growth of cellular and short range communication systems offer invisible but ubiquitous communication services that are essential for its services. User mobility and higher bandwidth requirements necessitated by these services drive the advances in communication technology towards more demand on spectrum resources. Therefore it is essential for P&GS systems to manage their spectrum allocation more efficiently. Furthermore emergency service systems need the possibility to expand in terms of capacity, coverage and as well as in interoperability to become more reliable and more robust in emergency situations and disaster monitoring.

Key issues and requirements that need to be addressed when introducing commercial markets to P&GS systems in related with these flexible spectrum management mechanisms are discussed in this work. This is based on an analysis of use case study with respect to a disaster monitoring emergency situation. In this paper spectrum negotiation between P&GS systems on a short term basis is investigated with respect to dynamic traffic parameters such as variance and correlation factor. It can be seen that traffic variations between systems play an important part in short term spectrum negotiation compared to the traffic correlation.

Key words; P&GS systems, interoperability, flexible spectrum management

1. INTRODUCTION

In current commercial and P&GS systems the spectrum is pre-assigned by authorities (such as FCC) for specific use. In the case of pre-assignment of the spectrum, at the physical level the usage of different systems determine the access mechanisms to the assigned spectrum segment. The following three approaches, identified in literature, can be considered as a way of efficient usage of spectrum in P&GS systems [1] and [2]. The first approach of flexible spectrum management in P&GS systems is the gradual introduction of the secondary markets in to the existing P&GS systems. The second approach, spectrum leasing by P&GS systems towards commercial systems and the final and the most ambitious approach of the use of Cognitive Radio (CR) technology in introducing commercial systems to P&GS systems. The challenge of these three different approaches is to provide flexible spectrum management that can be used in public safety systems, at the same time fulfilling the P&GS requirements.

The first case is the usage of secondary market model for public safety licensed spectrum. FCC recognizes that more robust secondary markets will help promote spectrum efficiency and full utilization of the licensed spectrum. FCC defines secondary market as the ability of the license holder to lease its (license holder’s) spectrum rights for the secondary entity. P&GS systems rely on spectrum allocated by the FCC for use in public safety agencies. At the moment FCC regulation prohibits public safety licensees from providing public safety spectrum to non-public users. As government sector requirements increases for mobility and real-time access with higher data rates it is likely that the public sector could emerge as a candidate for secondary market to any other government sectors. Is has been known in literature that during normal day-to-day functioning public safety networks uses only about 50% to 60% of its channel capacity at any given time. [1]. This is due to the fact in P&GS systems the spectrum resources are stockpiled to be available for deployment during emergency and disaster situations. Therefore P&GS systems have unused spectrum resources on day to day basis.

The second possibility is instead of forming the secondary market within the government sector the secondary market could emerge from the commercial sectors. Especially with introduction of high data rate services requiring higher bandwidths, commercial sectors are always looking for more spectrum resources, even just for short term usage. On the other hand in both of these situations ruthless pre-emption policies need to be placed to retrieve spectrum resources if need arises due to emergency and disaster situations. Therefore introduction of secondary market strategies introduce efficient spectrum management, although it is a different matter for policy makers to put in suitable pre-emption policies for the retrieval of spectrum resources to the primary users when the need arises.

As in the third approach; with the introduction of CR technology the secure spectrum segmentation and the prioritization can be moved to higher layers. For example the mission critical public safety systems and the commercial systems can share the same spectrum segments via different policy mechanisms. Public safety systems with cognitive capability terminals can access the whole spectrum segments available to both commercial and public safety systems. Therefore in the case when the first responder networks in the public safety systems are overloaded then they can be deployed via the cognitive usage of identified ‘spectrum holes’ or unused spectrum sub bands, thus increasing the efficiency of the public safety systems. This can be improved more with the introduction of pre-emption policies encouraging move out of commercial services from the spectrum segment giving way to the high priority public safety services. Also to make this more efficient significant policy considerations are needed with regard to reliability and the survivability of the cognitive spectrum resources. In this regard private commercial systems need to be compatible with the levels of reliability and the redundancy of public safety systems.

2. SCENARIO DEFINITION AND USE CASE ANALYSIS

The following scenario is focused on the use of P&GS systems in the situation of a terrorist attack where the deployment of rapid Emergency Medical Services (EMS) is essential. More detailed analysis of these scenarios in terms of outline, narrative and the transmission history can be found in [4].

In the event of an enemy attack initially the Information Centre (IC) is set up by the Law Enforcement (LE) organizations or first responders to the scene. This gradually evolves into the Joint IC, a unified command centre which is responsible for forwarding information and data from the Core Network to the mobile terminals. These may be in terms of authorizing and registering units that arrive on the scene, allocating tasks to groups, checking personnel status, monitoring the incident area, gathering and processing information from wireless sensors and managing and coordinating units on the scene. The data communication capabilities of EMS and other LE agencies may need to consider the following factors in the case of interoperability between systems.

- Information transfer from the perspective of the user rather than from the network providers’ centric approach
- Fast regain of control in crisis situations rather than the expected or anticipated situations
- For fast regain of control data communication capabilities needs to be increased
- Current emergency systems does not guarantee data communication centric approach
- The existing standards such as GPRS or current 3G systems does not guarantee reliability in terms of communications
- Also in the case of disaster situations fixed communication structure (wire line or wireless) do not exists or either malfunctions
- In this respect systems with the following properties needs to be implemented
    - Support data communication
    - Ubiquitous coverage within the crisis area
    - Faster network deployment such as ad-hoc (instantly deployable wireless networks)
    - Guaranteed reliability
    - Robust techniques towards high security issues

In the current scenario situation each agency will be using its one legacy wireless technology resulting communication centre for each and every agency. Since there is no direct inter-agency communication the information gathered from different agencies cannot be processed automatically and as well as cannot be efficiently shared between systems. As an example, when the IC receives the clearance from the Explosive Ordinance Disposal (EOD) officer that the area is clear from explosives and safe for the fire fighters and the medical staff to go in, each agency needs to be separately notified through their own radio.

Another instance is that the Public Safety Communications Office (PSCD) is responsible for informing the IC of the status of field staff providing movement information of other more vital signs, location etc. This will be a stand alone entity for each agency making its resource allocation and management more difficult. The scenario’s vision of a unified command centre thus falls back to separate co-located command centres for each agency. Even then, each agency would be responsible for providing and deploying their own communication equipment making the unified command difficult to set up, within the required minimum response times in disaster situations.

The following use case has been derived from the above scenario with their transmission history attached to it. For example the transmission history contains parameters such as:

- Time ID to give the time line and duration
- Response information from Public Safety Answering Point (PSAP), Emergency Operations Centre (EOC), EMS etc…

- Transmission information such as type and network utilization/security
- Networks and comments indicating the involved networks in the scenario such as TETRA, TETRAPOL, 3G, Analog etc…
    - **Use case definition**: PSAP (emergency) calls received and contacts are made to dispatches
    - **Time Stamp**: T_1
    - **Actors involved**: PSAP, LE, Fire Services, Commercial Systems such as 3G, PSTN, IP systems
    - **Use case description**: Public uses commercial networks such as 3G, PSTN and IP based networks to access the PSAP (Public Safety Answering Point). The first responder services are the LE and the Fire services which are informed by the PSAP.

The above use case has been analyzed with respect to interoperability issues between P&GS systems and commercial networks, as presented in the following sections. The first case looks into the current situation where there is no interoperability between systems. The next case focuses on where interoperability between P&GS systems is introduced with the use of cognitive approach. Finally more ambitious and challenging case is presented where interoperability between P&GS systems as well as cognition among commercial systems are anticipated.

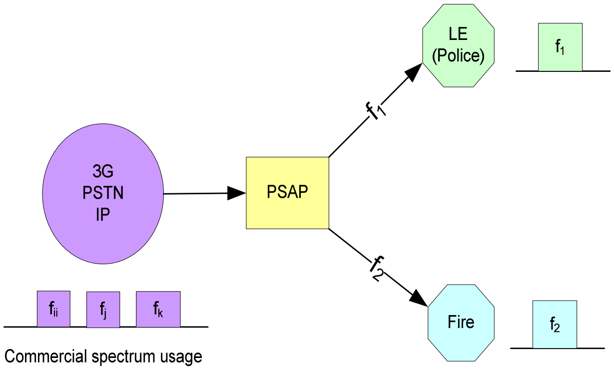

Figure 1 Current use case without interoperability between public safety systems

In the current situation [Figure 1] LE agencies and Fire services deploy their systems in different spectrum bands (frequencies f_1 and f_2). In this case each agency will be using its own legacy public safety system technology so there needs to be a communication centre for each one. The information gathered from law enforcement agencies cannot be processed automatically and there can be no direct inter-agency communication.

In this case there is no interoperability between the two systems. For example PSAP needs to communicate between the LE and Fire services separately as there is no direct communication between LE and Fire services. On the other hand LE service and Fire service need to rely on the available capacity in commercial systems. But in disaster situations it is anticipated high volume of traffic in commercial systems. Also GSM/3G/UMTS service is even stopped by network operators to avoid the enemy usage.

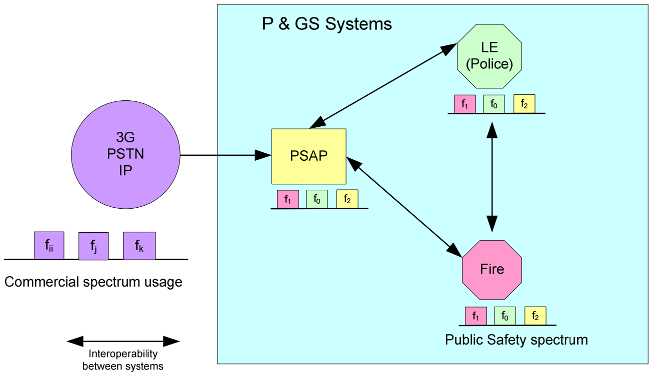

Figure 2 Interoperability between P & GS Systems with the use of cognitive terminals

The use of cognitive capability terminals reduces the problem of interoperability between law enforcement authority networks. As shown in Figure 2, if public safety systems (such as LE, Fire etc…) have the cognitive capability of tuning to other existing agencies this introduces faster response times and efficient usage of the spectrum. The scenario's vision of a unified command centre is achieved trough the use of cognitive terminals which can be interoperated in each others' systems. Rather than each agency being responsible for providing and deploying its own communication equipment, single unified command can be achieved especially within minimum response time required by the emergency situation.

These systems need to be compatible with cognitive radio attributes such as spectrum sensing, policy based operations and ability to rapidly change operating frequencies, power, bandwidth and waveform.

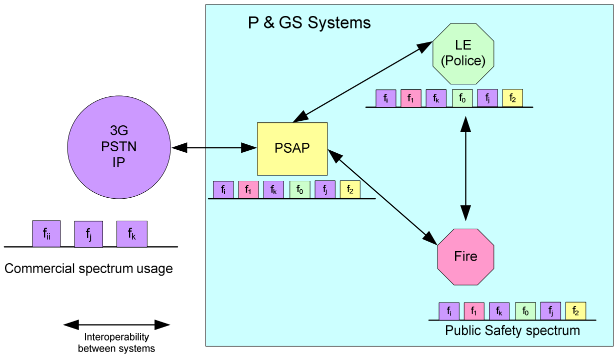

Figure 3 Interoperability between Commercial, P & GS systems with cognitive terminals

The above figure depicts the possibility of exploiting cognitive capabilities in situations where P&GS systems and commercial communication systems are involved.

Commercial communication systems are more suitable for high bandwidth applications and more appropriate with mobility and coverage issues. One such instance is use of commercial networks to transmit high data rate video applications (such as patient's visual images, injury status for medical operations etc…) used in EMS applications. Also cognitive use of commercial systems with P&GS may be used to bridge between network boundaries providing seamless connectivity between legacy systems for public safety used across counties covering larger geographical areas of disaster situations.

The requirement for interoperability raises particular issues; not only the various systems and waveforms within the P&GS systems range are expected to interoperate, but also P&GS systems and commercial as well as unlicensed systems will have to be able to communicate with each other. Fast call set-up times; group communications support; direct mode operations between radios; packet data and circuit data transfer services and excellent security features are some of stringent requirements that are necessary for robustness and reliability of public safety systems.

The following section describes how CR can enable a more optimized exploitation of the resources in such mixed P&GS-commercial-unlicensed deployment cases.

3.3. Sensing Requirements and Sensing Scope for interoperability in P&GS Systems

An important requirement of cognitive networks is the capabilities to sense and understand spectrum availabilities. CR is designed to be aware of and sensitive to the changes in its surroundings. The spectrum sensing functions enables the CR to adapt to its environment by detecting spectrum holes. The most efficient way to detect spectrum holes is to detect the primary users that are receiving data within the communication range of a CR user. In reality it is difficult to have the direct measurement of a channel between a primary receiver and a transmitter. Therefore primary transmitter detection based on local observations of the secondary (unlicensed) users is also important in the scope of spectrum sensing capabilities. Generally spectrum-sensing techniques can be classified as transmitter detection, cooperative detection and interference based detection [5].

Initial sensing scope will be the systems' own spectrum. Before sensing continues the secondary users need to be evacuated from the P&GS system. Sensing is a major part of cognitive radio network. Cognition capabilities of the P&GS system are based on the amount of intelligence known about the environment. Therefore more availability of intelligence leads to better cognition capabilities. On the other hand intelligence carries more processing power and energy consumption in the sensing architecture. Therefore it is more useful to look into other mechanisms of retrieving spectrum before continue in sensing techniques. This will in the end result in faster access of extra spectrum as well as energy consumption compared to spectrum access using sensing techniques. Therefore the following recommendations can be made for sensing scope on P&GS systems.

- Sensing will be restricted to the spectrum bands allocated for P&GS systems
- Frequency use from commercial bands may be anticipated but would be administered by the network management and control centre
- Sensing strategies should always start with consideration of the system own spectrum
- Secondary users should be removed before sensing being kicked in
- Rules on "avoiding sensing where possible" should be established

4. PERFORMANCE OF SHORT TERM SPECTRUM NEGOTIATION IN P&GS SYSTEMS

This section investigates the short term spectrum negotiation between P&GS systems as in a similar use case, depicted in Figure 2. In this study two systems (RANs) are considered with its own assigned spectrum. During an emergency deployment both RANs are assumed to follow the similar traffic demand. The objective of this study is to investigate the impact of traffic parameters (variance and correlation factor) on spectrum negotiation between two RANs, see Figure 4.

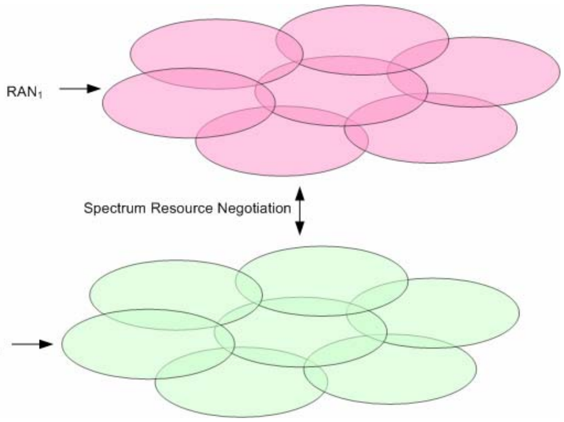

Figure 4 Spectrum negotiation between two RANs deployed with same RAT

4.2. Scenarios and Simulation Assumptions

This work considers two different scenarios each presenting different aspects of traffic distribution over the cell level in each RAN. Each RAN is assumed to consist of 20 cells with similar spectrum demand patterns. These scenarios are described as follows:

- In the first scenario, the average spectrum demand at the cell level is assumed to have the same, slowly increasing spectrum demand. The traffic demand (or in this case spectrum resource request) is non-correlated between RANs. The investigation is based on the impact of variance in the traffic patterns in each cell which perform spectrum negotiation. The performance is investigated for the variance factors of 0.1 and 0.2.

- In the second scenario the same cell topology is assumed but with correlation between traffic demand between the two RANs. In this scenario, the impact of the correlation between RAN networks load (spectral resource requests) at the cell level is considered for the correlation factors of 0.5, 0.7 and 0.9. Within this scenario the variance factors of 0.1 and 0.5 are investigated under different correlation factors.
- The spectral resources available for the RANs at cell level are represented as in the case of OFDMA base system in terms of time frequency (T-F) units.
- TDD mode is assumed, in which the usable sub-carriers are partitioned into 230 frequency units, with each super-frame containing 16 * 230 = 3680 T-F units. The total number of T-F units over all available carriers is denoted with S.

In the simulation model, the load on each cell is represented by the spectrum demand, expressed in number of T-F units (time and frequency units) requested in each super frame as in the case of OFDMA type of radio access technology (RAT). This is also referred as a spectral resource request (the unit of T-F units/super frame). The daily variations on average cell load are represented by the spectrum resource request average curves covering 24 hours.

4.3. Cell Level Spectrum Resource Request in each RAN

This section describes the spectrum usage pattern used for each RAN at the cell level. The amount of spectrum usage at the cell level for each RAN is calculated according to a simplified statistical model. The basic assumptions made in the spectrum usage pattern are as the following:

- Network load at each cell level is expressed in terms of number of T-F units requested per super frame. This is defined as spectral resource request d_i of the operator i, with the following properties.
- Random spectral resource requests are considered. In the case of random requests, they are samples from a cyclo-stationary random process with a period of 24 hours, and a truncated Gaussian distribution where the negative values were discarded, thus, creating a truncated distribution.
- Spectral resource requests are sampled over a period of 15 minutes, thus, resulting in 96 samples in total within 24 hours.
- Average spectral resource request at each cell level, $E[d_i(\tau)]$, where τ is the sampling instant, follows an arbitrarily selected curve over the period of 24 hours.

The selected curve is illustrated in [Figure 5], and is given by $E[d_i(\tau)] = D_i \, exp(-((\tau-\tau_d)/a)2)$, where parameter a defines the width of the curve. This curve is referred to as Gaussian bell curve within this work. The peak time of the day when the maximum value D_i is achieved is assumed as 12.00 hour or the 49th sample τ_d. The maximum value of average spectral resource request over the period of 24 hours is denoted with D_i. The correlation among spectral resource requests of the networks is related to the correlation coefficient c (when the requests are random). Depending on the scenario, correlation was varied in set of {0, 0.5, 0.7, 0.9}.

The standard deviation σ of spectral resource request di is varied proportional to $E[d_i(\tau)]$ with $\sigma = p \; E[d_i(\tau)]$. Depending on the scenario, p varies between 0.1 and 0.5, i.e., effectively switching between random spectral resource requests. These values present the cases where; in the first case, there is no lower randomness, and in the latter case, the variation on the spectral resource requests is very significant.

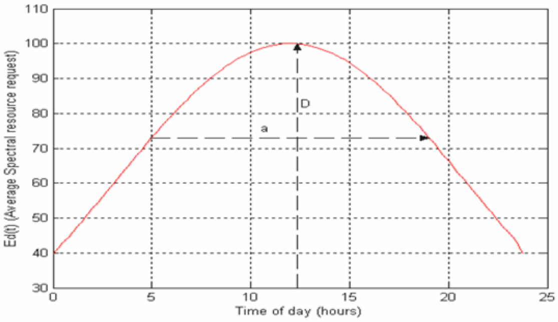

Figure 5: Average spectral resource request during a day

Performance of the schemes is measured with the metric number of extra T-F units available for negotiation. For the presented figures, the total number of extra T-F units available for negotiation between a cell pair is averaged over the 20 cells in each RAN topology. The extra spectral T-F resources available for negotiation correspond to the situation where the amount of allocated resources at cell level exceeds the offered load to the cell. The allocated spectrum resources come from the average spectrum demand value whereas the offered load to the cell is derived from the actual instantaneous spectrum demand values from the spectrum demand curves. The results for the explained performance metric is presented against the maximum average spectral resource request per cell, D, normalized with the number of total T-F units. In other words, the x-axis value 1 means that the maximum average spectral resource request over the day is 3680 T-F units in each RAN and each cell, and the total maximum average request over the RANs is 2 x 3680 T-F units.

5. DISCUSSION OF RESULTS

5.1. Impact of variance factor on spectrum negotiation

In this scenario the impact on traffic variance on spectrum negotiation in short term basis is investigated. The results are based on two different variance factors, for p = 0.1 and p = 0.2. Figure 6 and Figure 7 represents two different performance measures for the above case. Figure 6 presents the average spectral resource request for spectrum negotiation against the offered load (this is proportional to the maximum average spectral request *D*). The average spectral resource request is the mean of spectral resource request per cell (averaged over the number of cells) and per RAN (averaged over the number of RANs). It can be seen for normalized offered load in the range of 0.1 to 0.4 the increase of variance factor by 2 (from 0.1 to 0.2) introduces a small increase on the average number of extra T-F units available for spectrum negotiation. Once the normalized offered load is beyond 0.4 the relative increase of average number of extra T-F units available for negotiation is much higher. For example when normalized offered load is at 1 an increase in variance factor by 2 (from 0.1 to 0.2) results in 38% increase in the average number of extra T-F units available for spectrum negotiation.

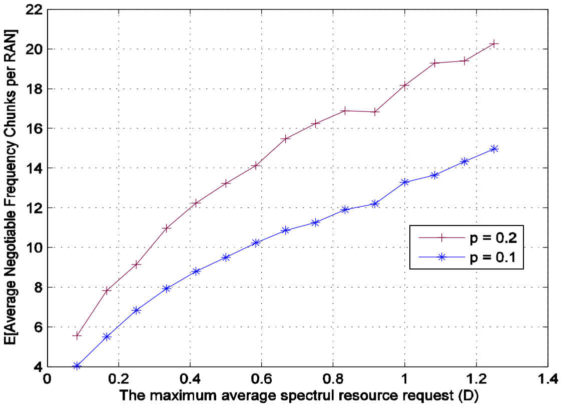

Figure 6 Average Negotiable Frequency Resources available for different variance factors (p =0.1, 0.2) with no correlation between RAN traffic

Figure 7 presents the total number of frequency T-F units available for spectrum negotiation per RAN basis. Although in the case of higher normalized offered load the total available negotiable T-F units increases the usage of these T-F units may be limited due to inter-RAN interference originating from negotiation. Therefore increase of variance contributes towards successful negotiation performance by increasing the number of T-F units available for negotiation. The amount of available negotiable T-F units between RANs is an input to spectrum negotiation functionality. The usage of these negotiating T-F units in better spectrum negotiation performance is part of T-F scheduling, T-F management minimizing inter-RAN interference originating from this spectrum negotiation.

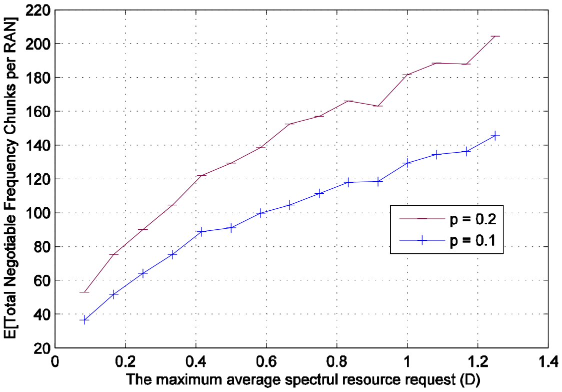

Figure 7 Total Negotiable Frequency Resources for different variance factors (p =0.1, 0.2) with no correlation between RAN traffic

5.2. Impact of correlation factor on spectrum negotiation

In the previous scenario two networks were assumed to have random uncorrelated spectral resource request. To have a closer look into the effect of randomness on the availability of average spectrum T-F units for spectrum negotiation, the impact of correlation between networks is considered in this scenario.

The following presents the number of spectral resources available for negotiation with different correlation factors. The correlation factors considered are values of c = 0.5, c = 0.7 and c = 0.9. This has been investigated for two cases of variance factors namely p = 0.5 and p = 0.1. Figure 8 and Figure 9 represents two different performance measures for the above case.

Figure 8 presents the average spectral resource request for spectrum negotiation for three different correlation factors (0.5, 0.7 and 0.9), for a variance of 0.5, against the offered load which is presented in the x axis as proportional to the maximum average spectral request (*D*). Figure 9 presents average number of T-F units available for negotiation initialization for different correlation factors (0.5, 0.7 and 0.9) between RAN spectral request and for the variance factor of 0.1. The average spectral resource request is the mean of spectral resource request per cell (averaged over the number of cells) and per RAN (averaged over the number of RANs).

As seen in the above scenario the impact of variance of spectral resource request plays a major role in the successful negotiation. But in the case of varying correlation factors it can be seen that the impact of correlation among traffic is not a major influence in negotiation procedure in spectrum negotiation.

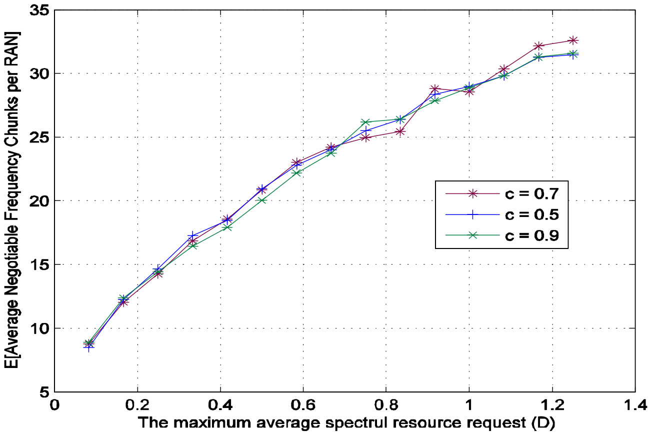

Figure 8 Average Negotiable Frequency Resources for different correlation factors (c = 0.5, 0.7, 0.9) and variance factor of p = 0.5

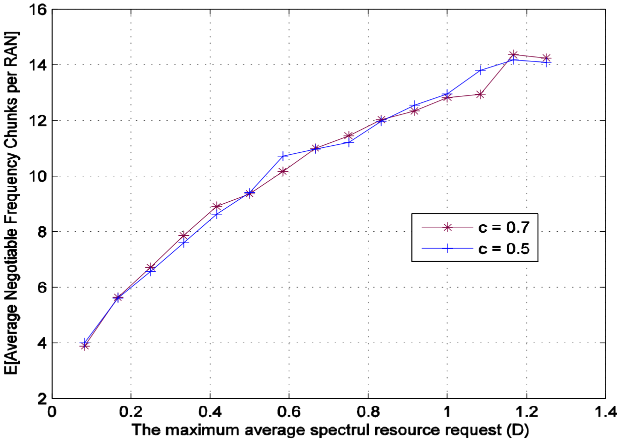

Figure 9 Average Negotiable Frequency Resources for different correlation factors (c = 0.5, 0.7) and variance factor of p = 0.1

6. CONCLUSIONS

This paper presents some of the key issues and requirements that need to be addressed when flexible spectrum management is introduced into P&GS systems. Apart from the above, issues related to sensing requirements and sensing scope are discussed with focus on facilitating interoperability in P&GS systems.

Also in this paper spectrum negotiation between P&GS systems on a short term basis is investigated with respect to dynamic traffic parameters such as variance and correlation factor. Even though the impact of variance of spectral resource request plays a major role in the successful spectrum negotiation, in the case of varying correlation factors it can be seen that traffic correlation does not play a major influence in spectrum negotiation. At the same time higher variances in the offered traffic load patterns creates more opportunities for spectrum negotiation.

7. ACKNOWLEDGMENTS

This work has been performed in the framework of the EU funded project WINTSEC. The authors would like to acknowledge the parts of this paper coming from contributions of their colleagues from WINTSEC consortium.

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