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Cognitive Radio Enabled Telemedicine System

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Abstract Appropriate pre-hospital-diagnostic, consultative and therapeutic facilities are important to improve deteriorating health conditions of patients especially those in transit such as an accident victim or a patient who had chest pain and being transported to a hospital. Telemedicine systems provide such timely facilities. We propose here a telemedicine platform architecture consisting of three tiers. The first tier made up of body sensors connected to a gateway and the communication technology used in this tier is UWB. The third tier of the architecture is the communication link between the mobile vehicle and the hospital, which is a cognitive radio enabled communications system. A cognitive radio controller chooses a free spectrum that can provide a reliable communication link for a secondary user. The cognitive radio controller and the gateway integrated together forms the second tier of the architecture. The UWB based sensors on the first tier are capable of improved performance with negligible impact of interference. The performance metrics of the cognitive radio is given in term of region of convergence. Results verify that the proposed light-weight combination strategy can improve free spectrum detection performance significantly under both urban and suburban environment.

Keywords Mobile telemedicine system · Mobility driven cognitive radio · Spectrum sensing · Hard-decision combining strategy

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1 Introduction

Telemedicine systems can provide pre-hospital healthcare facilities to critically ill patients by measuring their bio-signals, conducting suitable pathological tests and communicating results to a doctor or healthcare expert for diagnosis and medication. This can be extremely beneficial especially for critically-ill in transit patients, passing through a critical phase. Their health could be significantly improved by providing timely medical support with the consultation of a doctor prior to reaching a hospital or health care unit. For example, patients with cardiac-illness, which is the highest cause of mortality and morbidity in USA, could be substantially improved by providing appropriate timely medical care such as giving immediate defibrillation to arrhythmia patients [1]. Studies show a phenomenal 43 % survival to discharge ratio in cardiac-arrest patients who were provided pre-hospital ambulatory defibrillation [2].

The death rate due to cardiac-related diseases is currently 12.2 % which is expected to remain the same even by the end of 2030. Besides, an increase in deaths due to traffic accidents in coming decades, which stood at 2.2 % in 2004 is estimated to reach 3.6 % in 2030 [3]. In these and other cases [4] a significant number of lives, expired during transportation, can be saved if timely and adequate medical support are available during transport. This will not save precious human-lives but also decrease health-care cost. Telemedicine system in addition to providing essential medical facilities to critically-ill patients, gives an opportunity to drivers to reach the nearest hospital with adequate facilities and vacancies [5]. This can be enormously useful especially in case of disasters and natural calamities, when the nearest hospitals are not able to serve the increased number of emergent patients.

Typical telemedicine systems consist of three-tiers [6], as shown in Fig. 1. The first/intra-WBAN tier consists of biomedical sensors where bio-signals are measured. The second tier is a gate-way which processes the bio-signals and sends it to hospital or healthcare facility. The communication link between the gateway and the hospital or healthcare facility forms the third-tier. In the existing systems, second-tier works as a

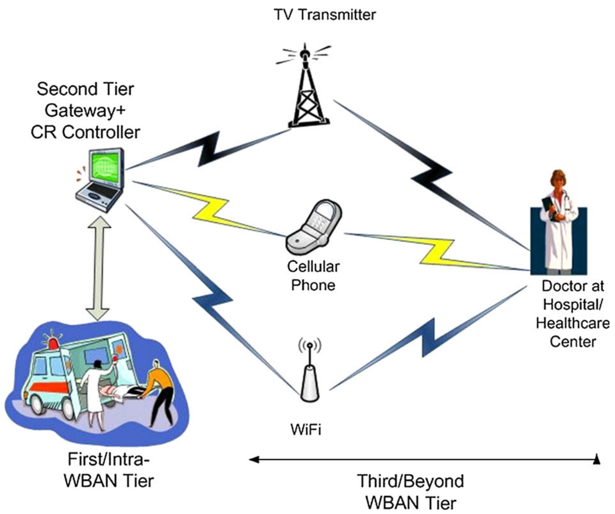

Fig. 1 Proposed architecture for cognitive radio enabled ambulatory telemedicine system

gateway, while in our proposed architecture it includes a cognitive radio controller to facilitate our third tier, the communication link between the gateway and the hospital or healthcare facility is a cognitive radio based communication system.

Most of the proposed and developed telemedicine systems use narrowband transmission technologies in intra-BAN tier such as Bluetooth, low energy Bluetooth (BLE) and Zigbee (802.15.4) [7]. However, due to co-users of ISM band such as microwave oven, Bluetooth and WLAN, the transmissions face harmful interference. This interference results in higher Packet Error rate (PER) which affects directly the link reliability and indirectly the battery life of the system [8]. Thus a robust scheme is needed that can successfully complete its transmissions under the existing conditions. Energy consumption requirements of Zigbee and BLE systems are low in comparison to its peers but not low enough to supply through energy scavenging. For energy scavenging the energy requirement should be $<100\ \mu W$ [9]. So, an efficient transmission technology is required which could draw energy ubiquitously through energy harvesting.

A critical issue on third tier of the telemedicine system is the seamless connectivity required to connect the mobile telemedicine system with a hospital or a healthcare facility.

We propose a cognitive radio based telemedicine system. The proposed system utilizes ultra-wide band (UWB) transmission system on first tier. UWB based system, in comparison to narrowband, provides lower power consumption, better interference-resistance capability in addition to data security. Energy scavenging can satisfy the energy requirement. Cognitive radio is used on the third-tier to provide seamless connectivity between mobile telemedicine system and hospital or healthcare facility. Cognitive Radio is a novel concept that exploits the unused spectrum bands (white spaces) in an efficient manner, thus providing ubiquitous connectivity with better quality of service (QoS) in a cost-efficient manner. An overview of mobile telemedicine architectures along with challenges is presented next.

1.1 Prior Work

In this section we present a summary of mobile (ambulance based) telemedicine systems with challenges. In [4], authors have presented a mobile telemedicine system for emergency healthcare service to patients. The telemedicine system transmitted critical bio signals and images of patient to hospital for tele-diagnostic, tele-therapeutic and tele-consultative purposes. Global System for Mobile (GSM) telephony network (with maximum data rate of 9.6 kbps as of 1998) has been used for communication between ambulance and healthcare staff. The system consisted of a bio signal monitor and a portable PC with attached camera for capturing still images of patients. In [5], authors proposed an ambulance based telemedicine system providing wireless access through a Quasi-Zenith Satellite (QZS). QZS will have almost 12 years of active operation. An estimation of the impact of the proposed ambulance based telemedicine system on Japanese society showed significant improvement in average life-saving rate, which could be from as little as 3.35 % to a significant 11.40 % per year, that translates into a saving of almost 6700 precious lives out of 84,000 cardiopulmonary arrest patients each year [5]. It is estimated that the proposed system can save a total of 80,000 lives in proposed time span. The telemedicine system also provide suggestions to help ambulance driver in reaching the nearest hospital with the required number of vacancies and available health facilities to save travelling time, which has a direct impact on saving lives. In [10], the authors have successfully developed and tested an ambulance based telemedicine system that provides tele-health facilities using 3G network. The system consisted of a notebook with camcorder and PCMCIA card or a 3G phone to connect to a distant hospital. To quantify the network performance of the proposed platform, two network monitoring programs were run during testing phase of the ambulance based telemedicine system. One showing type of network connection and connection speed while other for displaying specific network parameters including channel utilization, packet size, protocol usage and continuous network speed. The experimentation was performed in Athens, Greece. During trial runs, the performance of telemedicine system was quite satisfactorily especially when the system was connected with both 2.5G and 3G cells at the same time. However, during handover phase between the two cells of different generation systems, the system remained disconnected for 17 min out of 24 h operation. A laptop and a camcorder were used to transmit still images and results of Thyroid Function Test to a hospital through 3G network. However, transmissions of X-rays, Computed Tomography scan, Magnetic Resonance Imaging etc. proved to be a difficult task. In [11], authors proposed a multi-conference telemedicine system to facilitate ambulance based users in receiving tele-consultation from several doctors or healthcare staff at the same time. The IP based system was developed on 3G to provide such facilities. In William Walker et al. [12] developed a mobile health system known as Remote Mobile Monitoring System (RMMS) for a bicycle rider. Biometric and environmental information of the rider were acquired by low power sensors and stored in a remote database that was accessible to remote users through internet. The RMMS can be used to measure heart rate, oxygen-saturation of blood, temperature of the rider and speed of the vehicle. A sensor module, BioTE, was also developed by the same authors, which consisted of a two chip wireless solution including a microcontroller and a RF Transceiver system. The proposed system can also be used in diagnosing ambulatory patients and monitoring soldiers in battlefield. In [13] authors present a pre-hospital telemedicine system to cope with emergency situations arising from disasters. The system integrates many bio signal-sensing devices with a tablet PC that is then connected with a central server using EVDO (A high speed 3G Standards) service.

Studies into ambulatory telemedicine platforms reveal that most of the existing systems use either wired or wireless narrowband system on the first tier. Wireless systems are preferred over wired systems due to scalability and flexibility. However, the narrowband systems operate in ISM band, sharing with other unlicensed users such as WLAN and microwave ovens. There are also challenging issues in the design of energy efficient MAC protocols to prolong battery life of the systems in the first-tier and, interference and seamless transmission with specified QoS on the third tier. Our proposed architecture addresses most of the pressing issues by using UWB transmissions on first tier and exploiting TV white spaces on the third tier using spectrum sensing cognitive radio (CR).

1.2 Main Contribution and Paper Organization

We present a novel architecture to address challenging issues faced by existing telemedicine platforms for ambulatory users (Fig. 2).

UWB system is proposed on the first tier of the proposed system to address energy consumption, interference and secure transmission. Mobility driven CR is attached to the gateway forming the second tier of the telemedicine system to connect mobile system with hospitals or healthcare facilities. The third tier of the telemedicine platform is thus a cognitive radio based system. Performance of the system is quantified in TV White Spaces (TVWS) in a dynamic fashion. In section II we present a novel mobility-driven CR based telemedicine architecture that addresses most of the issues discussed in preceding section. In section III, performance analysis of the proposed system along with numerical results is presented. Conclusion is given in section IV.

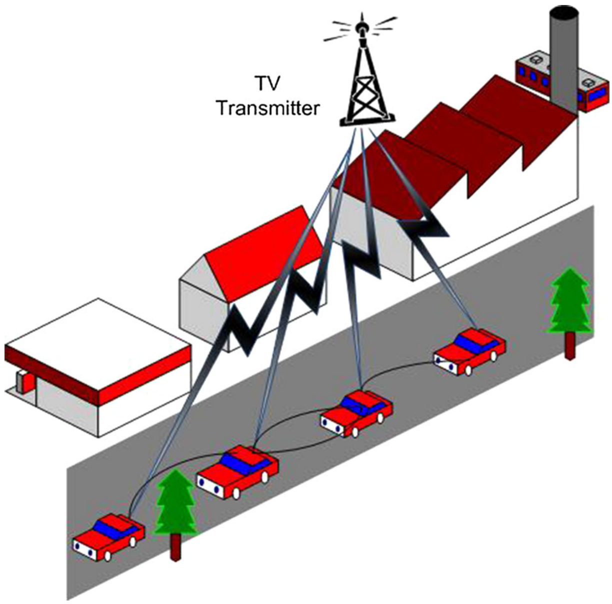

Fig. 2 New architecture for mobility-driven cognitive radio: exploiting cooperation among vehicles

2 Proposed Architecture for Cognitive-Radio-Enabled Mobile Telemedicine System

We propose a three tier Cognitive Radio (CR) based telemedicine system that uses UWB on the first tier. UWB works on higher data rate and secure applications and is capable of energizing through energy scavenging. The second tier consists of a gateway for connecting tier-one sensors and a CR controller for providing seamless connectivity between the gateway and the hospitals or healthcare facilities forming the third tier of the architecture. The CR provides the required QoS between the gateway and the medical facilities.

2.1 First/Intra-WBAN Tier

First/Intra-WBAN tier of a typical telemedicine platform consists of invasive and non-invasive sensors, attached to human body for measuring vital signs including pulse rate, blood pressure, ECG, EEG etc., periodically or continuously to identify any irregularities. Sensors measure bio signals and submit those to the second tier/Gateway-CR Controller. Gateway collects all the measured bio signals, processes the raw data so that a minimum of data could be transmitted to the hospital/healthcare unit. After receiving the data from the mobile telemedicine system, doctor/healthcare expert diagnoses the patient and suggests an immediate pre-hospital treatment, which is then administered by the healthcare professional in ambulance. We propose the use of UWB based transmissions between the sensors and the gateway. UWB is an ultra-low power and high data rate radio standard, using transmission bandwidth of approximately 500 MB. Message is spread into carrier in such a fashion that it looks like noise to coexisting users of the band. This provides additional benefit of secure-data transmission to the data that is life-critical. In addition, it is an energy efficient, high data-rate, low cost [7], coexistence-friendly and lower electromagnetic radiation based system [14]. UWB can transmit in both ISM band and

3.1–10.6 GHz band. Due to higher data rate it can also be used to transmit video, audio and medical data such as ECG, EEG, heart rate etc. from a patient's WBAN sensors to the gateway. Typically an EEG with 256 sample require 131.1 kb/s, ECG with 300 Hz sample requires 72 kb/s and EMG with 8 kHz sample requires 1.1 Mb/s [15]. In the following discussion, we explain distinct features offered by a UWB based system.

2.2 UWB for Intra-WBAN Tier

In this section, we elaborate reasons for considering Ultra Wide Band Communications as the preferable technology for Wireless Body Area Networks.

(1) UWB based transmitter communicates in form of pulses as against narrowband systems that transmit continuously. Power Spectral Density of these pulses is very low and thus can be transmitted on the same spectrum as that of narrowband systems without any interference [16]. Thus critical medical data can be protected from harmful interference.
(2) UWB transmitter can be implemented using digital circuits, thus the chip area of UWB transmitter can be smaller [17]. This makes small-sized efficient transmitters for WBAN communications possible.
(3) DVB-T, the popular standard of Digital TV broadcasting for digital terrestrial television has transmission rates in the up to range of 5–32 MB/s [18]. Real time video traffic of high quality compatible with DVB-T can be achieved through UWB, whereas not possible through Zigbee.
(4) In UWB transmission, the data is spread, which results in very low impact by narrowband interferers on the UWB transmissions. The UWB proves to be a reliable technique for transmission of WBAN parameters. Besides, due to short pulses of 2 ns, multipath components are easily resolved [].
(5) Due to accurate ranging measurement capability, UWB can also be used for medical imaging [14].

2.3 Energy Consumption

Efficient communication requires low power transmissions in the first tier so that the sensors could remain active without external power supply for a long time. One possible method is energy scavenging. Considering the power requirements of narrowband systems, Bluetooth requires 0–100 dBm and Zigbee −25–0 dBm [7], it is not possible to operate these systems by energy harvesting (Fig. 2). However, UWB systems, with very lower transmit power requirements i.e. 19 µW [19] or (−41.3 dBm/MHz) [7] can effectively work for years by harvesting energy from solar, thermal and other environmental sources. In addition, more designs are under research and development which require even lesser transmit power, one such design requires 19 µW at a data rate of 100 kb/s with BER 10^{-5} and receiver sensitivity of −81 dBm [19]. This gives impetus to the UWB research as one of the most suitable candidate for future bio medical sensors [9].

2.4 Bandwidth

Bluetooth systems operate on maximum of 0.72 Mb/s; Zigbee systems operate at a maximum of 0.25 Mb/s whereas UWB systems operate at a maximum of 110 Mb/s [7]. The comparison shows that the Wideband Systems are not only capable of transmitting bio-signals of any type including pulse rate, EEG,ECG etc. but can also be used to transmit audio and video type data as well. However, its competitor Zigbee and Bluetooth cannot [7].

2.5 Interference Issues on Unlicensed Band

Narrowband systems, used for communication on intra-WBAN layer coexist with other users such as WLAN, Microwave etc. on ISM band. Studies show that near-by activity can severely affect the performance of narrowband systems on WBAN tier.

In this regard, impact of WLAN interference on Bluetooth devices is quantified in [20], shows 12 % packet loss in Bluetooth voice traffic under different WLAN packet lengths. In [8] interference impact of WLAN, Bluetooth and Microwave ovens on Zigbee is reported. The WLAN with usage duty cycle of just 10 % shows deteriorating impact on Zigbee users. Microwave ovens operating in 2.45 GHz if operated in close proximity can also cause harmful interference to the users. Retransmissions requirement due to microwave ovens' interference have a significant impact on the performance of Zigbee systems. However, Bluetooth systems do not pose a great threat to the Zigbee users [8].

The scheme is complex and controls over vicinity wireless devices are not always possible. Our proposed system uses UWB based transmission system, through impact of interference from narrowband transmissions is unavoidable but can be mitigated by the techniques such as stated in [21].

2.6 Electromagnetic Radiations to Human Body

Due to low power radiations, UWB is friendlier towards human body. Studies on UWB for imaging as an alternative to conventional NMR or X-ray medical imaging were done from as early as 1990 and they all demonstrate safe use of UWB on human body [14].

2.7 Second/Inter-WBAN Tier

In typical telemedicine systems, WBAN gateway forms the second tier that collects the bio signals of all the sensors attached to a patient, and processes the raw data so that a reduced and the more significant data can be transmitted to the hospital. Typically a laptop or a smart phone can work as a WBAN-gateway. Our proposed system uses WBAN-gateway integrated with a Cognitive radio controller. The cognitive radio controller does spectrum sensing on the third-tier of our telemedicine architecture consisting of both licensed and unlicensed spectrum that can be exploited in a a secondary manner to provide communication between the gateway-CR controller and the hospitals. The distinct features of the proposed cognitive-radio system are discussed briefly.

2.8 Third/Beyond-WBAN Tier

2.8.1 Spectrum Sensing Cognitive Radio

Increased use of wireless communication devices added with new and innovative wireless technologies require more RF spectrum. However, due to limited natural resource, the industry faces the spectrum scarcity issues. The spectrum utilization report [22] shows underutilization of spectrum in 3–6 GHz band. The Federal Communications Commission (FCC) findings [23] also states that the spectrum utilization is only 15–85 %. Consequently FCC issued a Notice of Proposed Rule Making [24] for secondary usage of spectrum through spectrum sensing Cognitive Radios. Cognitive Radio is a novel concept that exploits unused spectrum holes in time, frequency, space and Code domain by detecting bands intelligently. Spectrum hole refers to the band of frequencies pre-allocated to a primary user, presently available for use in time and geographic area. Identification of unused spectrum spaces in time and cost efficient manner is a key step in realizing intelligent and efficient radios. Spectrum sensing can be performed through a number of algorithms that include matched filter, energy detector and Cyclostationary detector [25]. Matched filter is an optimal detector because it maximizes Signal to Noise Ratio. This comes at the cost of knowing the received signal because matched filter demodulates the received signals. Energy detector is a sub-optimal non-coherent method of detecting white spaces. However, selection of a threshold for sensing is a critical issue due to noisy environments. Cyclostationary detector is capable of not only detecting the presence or absence of a spectrum hole (white space) but can also efficiently identify the type of signals. Thus using these detectors one can easily identify type of signals, interference, and noise separately. However, this could be achieved at the cost of complexity. Cooperative Sensing is a technique where more than one secondary radio combines their sensing outcome to come up with a decision regarding the presence/absence of a spectral hole. This can be helpful in shadow-fading environments when a single radio is unable to decide. In the IEEE 802.22 standard, the spectrum sensing will be done in two stages i.e. fast sensing and fine sensing The fast sensing will be performed using Energy detector [26].

2.8.2 Cognitive Radio for Vehicular Channels

CR based devices can play an important role in improving the communication quality between V2 V (Vehicle to Vehicle), V2I (Vehicle to Infrastructure) and I2 V (infrastructure to Vehicle). Cognitive Radio intelligently detects white spaces and exploits those efficiently, thus, providing seamless connectivity to end user. Use of artificial intelligence in Software Defined Radio (SDR) for efficient spectrum sensing and communications has also been demonstrated [27].

Performance analysis of Cognitive Radio for moving vehicles has been reported in [28, 29]. The CR architecture proposed here senses unused spectral bands by simple energy detectors. In addition, probability of miss detection is derived in terms of number of sensing required by a detector to sense before deciding the presence/absence of a licensed user. Also the impact of probability on average received SNR for different vehicular speeds in urban and suburban environment have been computed. The performance metrics are derived using exponential correlation function model [30].

2.8.3 Fusion Center

Decision combining is shown to improve detection probability under fading conditions [31]. Besides, it also helps in lowering the SNR Wall [32] which is the signal to noise ratio level below which signal detection is not possible. Sensing results can be combined by using Soft, hard and hybrid techniques [33]. In Soft combining techniques, such as Maximal Ratio Combining, Equal Gain Combing etc., individual radios submit sensing results to a fusion center where results are combined. In hard decision combining, each radio transmits one bit (1 or 0) hard decision to fusion center where the results are combined for the presence or absence of licensed devices. Hard decision combining can be performed using AND, OR, n-ary and m-out-of-n rule [31, 34]. Results in [35] show significant improvement in detection probability for soft combining methods over hard decision. We use light- weight hard decision based strategy to combine the results of several sensors about the presence of a primary user under shadowed channel conditions. The results show significant improvement in comparison to individual sensor detection. Hard decision based combination strategy is optimal if the sensors are independent and identically distributed.

3 Performance Analysis

We consider energy detection based scheme for identification of unused spectrum bands (White Spaces) in Broadcast bands. Cognitive Radio (CR) is attached to the mobile vehicle. It is also assumed that during sensing interval the vehicle moves in the same direction. Performance is computed using exponential correlation model for shadowed fading.

Assuming Y as the received signal strength with following statistics:

$$\mathbf{Y} \sim \begin{cases} \mathbf{N}\left(\mathbf{P_n}, \dfrac{\mathbf{P_n^2}}{\mathbf{m}}\right); & \mathbf{H_0} \\ \mathbf{N}\left(\mathbf{P_s}+\mathbf{P_n}, \dfrac{(\mathbf{P_s}+\mathbf{P_n})^2}{\mathbf{m}}\right); & \mathbf{H} \end{cases} \tag{1}$$

where $\mathbf{P_s}$ is the received signal power from a primary user and $\mathbf{P_n}$ is the noise variance, m = TW is the product of time and bandwidth and P is the received power from PU.

Consider y as a multivariate Gaussian random variable, $y = [y_1, y_2, y_3, y_4 \ldots y_n]^T$ having N measurements with its joint distribution given by:

$$\mathbf{y} \sim \begin{cases} \mathbb{N}(\boldsymbol{\mu}_0, \sum_0); & H_0 \\ \mathbb{N}(\boldsymbol{\mu}, \sum); & H \end{cases} \tag{2}$$

where $\boldsymbol{\mu_0}$ and $\boldsymbol{\mu}$ are the values of mean and $\boldsymbol{\Sigma_0}, \Sigma$ are the covariance matrices of received signal $\mathbf{Y}$ under hypothesis H_0 and H respectively,

$$\boldsymbol{\mu}_0 = P_n \times \mathbf{1}, \quad \boldsymbol{\mu} = (P + P_n) \times \mathbf{1} \tag{3}$$

$$\boldsymbol{\Sigma}_0 = \frac{P_n^2}{m}\mathbf{I_N}, \quad \boldsymbol{\Sigma} = \frac{P_n^2}{m}\mathbf{I_N} + \frac{2PP_n}{m}\boldsymbol{\Lambda} \tag{4}$$

where $\mathbf{I_N}$ is a N $\times$ N Identity matrix and $\boldsymbol{\Lambda}$ is a N $\times$ N covariance matrix which is defined as $\Lambda_{12} = \rho^{|p-q|}$ p, q = 1, 2, 3, …… N; And $\mathbf{1}$ is a column of ones and $\rho = e^{-av\Delta t}$ is a correlation coefficient between two sensing positions, with v the speed of vehicle and a is a constant depending on environment. Assuming interference signal in null hypothesis i.e. $\Sigma = \Sigma_0$ as in. This assumption makes the derivation of detection probability computationally simple. Using log likelihood ratio, probability of detection can be defined as

$$\mathbf{P_D} = \mathbf{Q}(\mathbf{Q^{-1}}(\mathbf{P_{FA}}) - \mathbf{P_R}\sqrt{\mathbf{1^T}\Sigma\mathbf{1}}) \tag{5}$$

where P_D shows probability of detection, P_{FA} represents probability of false alarm, P_R the received power and $\Sigma^{-1} = \frac{m[1+2\gamma\Lambda]^{-1}}{P_n^2}$ and γ is the received signal to noise ratio.

3.1 Numerical Results

In this section, we evaluate performance metrics for mobility driven spectrum sensing CR. Complementary ROC under urban and suburban environments under exponential correlated shadowing is plotted for various settings. $P_{MD} = 1 - P_D$ represents probability of missed-detection i.e. $P_D = 1 - P_{MD}$ and P_F represents probability of false alarm. Q_{MD} and Q_F represent probability of missed-detection and false alarm under cooperative decision combining rule.

The parameters are taken from IEEE 802.22 Standard for Wireless Regional Area Network, $P_R = -114$ dBm, $P_n = -95.2$ dBm, T = 1 ms, W = 6 MHz, a = 0.12 in Urban and a = 0.002 in Suburban.

Probability of False Alarm is considered to be 10^{-3} unless otherwise expressed and t = 1 s.

In Fig. 3 the sensing results of a single sensor is presented under both urban and suburban environments.

Figures 4 and 5 show the impact of cooperation among vehicles for urban and suburban environments respectively. It is assumed that the fusion vehicle received the decision bits from partner vehicles without any deterioration and decides about the presence or absence of primary user (in this case tv transmitter) using Or based hard decision strategy. In the case of known correlation structure detection performance and hence Complementary ROC can be improved more significantly. However, it is assumed that only one bit information is available regarding presence or absence of a legitimate user. Even though, only a single bit hard decision strategy is employed probability of missed-detection is significantly reduced when seven cooperating users are considered in comparison to a single user case.

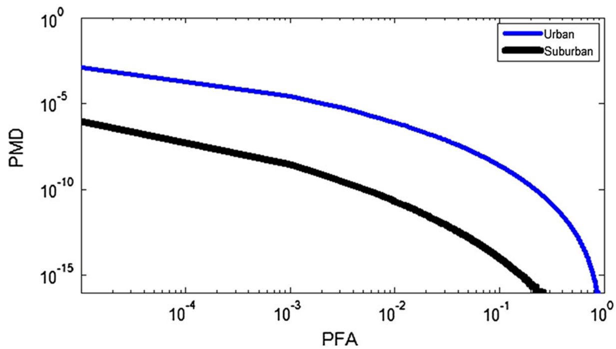

Fig. 3 Complementary ROC Performance at vehicular speed of 50 m/s under urban and suburban environment (P_{MD} is the Probability of missed-detection and P_{FA} is the probability of false alarm)

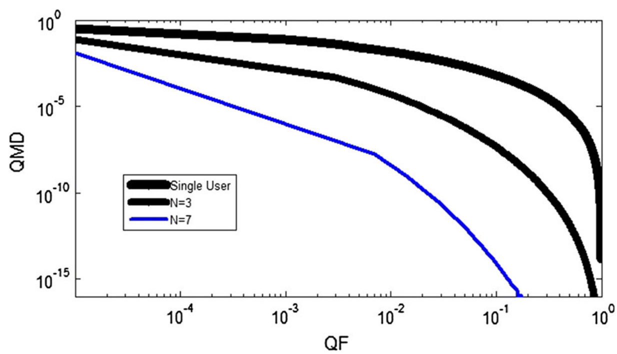

Fig. 4 Impact of cooperation among vehicles under urban environment

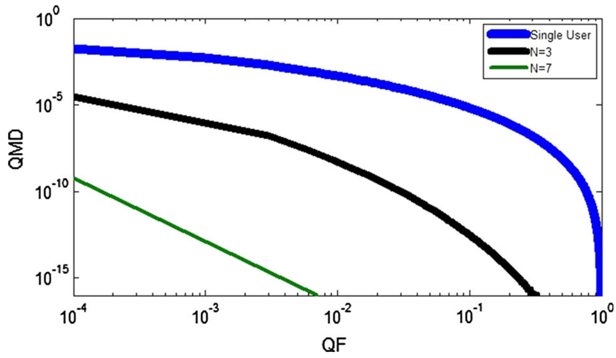

Fig. 5 Impact of cooperation among vehicles under suburban environment

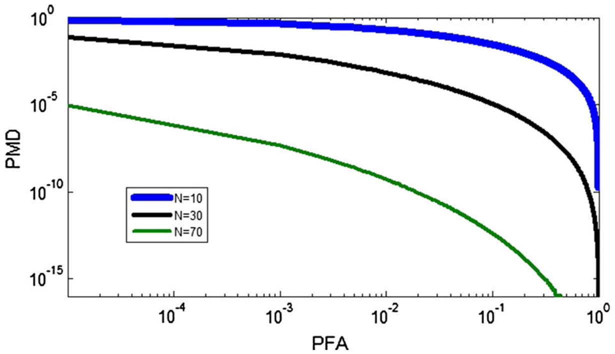

Fig. 6 The impact of number of sensing on cognitive radio under urban environment

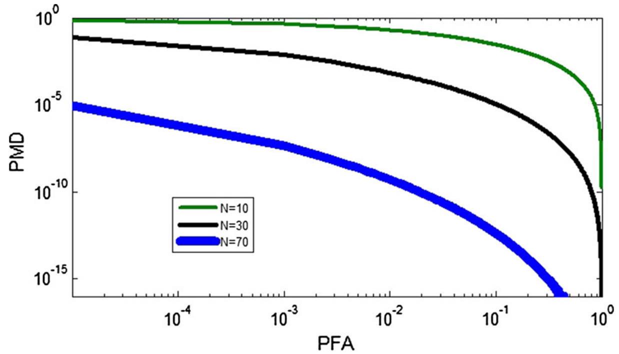

Fig. 7 The impact of number of sensing on cognitive radio under suburban environment

Figures 6 and 7 show the performance of spectrum sensor under urban and suburban environments respectively. It is shown that the performance of larger sensing is significantly better than smaller number of sensing as expected.

4 Conclusion

In this paper we presented a novel Cognitive Radio based telemedicine system for ambulance based system. The proposed platform uses UWB based transmissions on first tier and cognitive radio based gateway on second tier and the third tier consists of healthcare/hospital. It is studied that the UWB based system outperforms existing narrowband transmission systems such as Zigbee and Bluetooth. Due to low power transmissions on first tier, UWB systems can also operate through energy scavenging which can activate the proposed system up to years without external power supply. Complementary ROC is plotted for several cases under urban and suburban environments. A novel cooperative sensing strategy is also proposed, results show that the proposed strategy outperforms existing single sensor schemes significantly by exploiting spatial diversity.

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