Non-Cooperative Game Theory Approach for Cognitive Cooperative Communication in WBAN

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***Abstract*—To increase the Quality of Service (QoS) of wireless body area network, we need an effective data-rate delivering method, which capably forwarding the data over several path. For this reason, we proposed a non-cooperative game approach, based on utilizing a pricing-based spectrum leasing mechanism to transmit the data over several path based on non-cooperative game theory. The parameter price c is together determined by WBAN sensor and D2D users. Then, all selected D2D users used optimized powers that can fulfil the need of the WBSN users. Numerical results show the proposed approach improves the utility of WBSN users and their throughput.**

Keywords— **WBSN, non-cooperative game theory, optimal power allocation, transmission rate.**

I. Introduction

Wireless Body Area Network (WBAN) is a star topology wireless network. For monitoring the vital physiological signals, such as ECG signals, blood pressure, body posture signals, WBAN has to contain a coordinator and multiple sensor nodes operating on, in or around the human body.[1] In order to heath monitor, WBAN is vastly adopted with the development of communications, micro -electronics, integrated circuit technology, the ardent expectation of people's health as well[1].

The physiological signals were collected and sent to the remote medical center for health management and disease treatment by the coordinator. When WBAN systems is designed, there are some issues require careful considerations because of the WBAN topology's specialty and application.

Firstly, the energy efficiency should improve since the energy consumption is sensitive in WBAN. Which it is impossible or too hard to exchange the battery powered in sensor nodes. Secondly, the health monitoring has to ensure the Quality of Service (QoS) of WBAN, as well as, the significant of acquiring and transmitting the vital physiological signal while trying to reduce the energy consumption[2][3][4].

Wireless Sensor Networks (WSNs) are sometimes referred as short range WSN. So, it would be considered that the WBAN is a particular case of WSNs. WBANs are sometimes referred as one of the most promising technologies in a near future because of high efficiency and convenience for noninvasive monitoring are provided by WSN[4][5].

A wide variety areas enable the application of WBAN features as an emergent network technology. Such areas are; sports, healthcare, assisted living, disaster relief, military and Augmented Reality (AR) scenarios. The idea of this technology is based on wearable sensors network (edge of the network devices), communicating with each other at a short range (around 5 m), as depicted in Fig. 1. Variable rates (from 10 kb/s to 10 Mb/s) are required to be handel by the network technology, according to the application requirements and data to be acquired[2] [6]. The nodes can gather specific data, such as vital signs, movements and body posture or environment parameters. Network coordinator or gateway is refering at the use of wireless communication technologies, and deliver the information to a sink node. Which is responsible to forward the information or to perform longterm and continuous monitoring [1][7], as shown in the general architecture in Fig. 1. This architecture enables the integration of different technologies in one distributed intelligent system, designated Cyber-Physical System (CPS), which aims to process the information centrally, collect data globally, and distribute the results locally[8].

The resultant technical aspects in term of communication reliability and latency in transmission, provide valuable insight into the design and implementation of WBANs. A specific standard for low power devices and operation on, in or around the human body are developed by The IEEE 802.15 Task Group 6 (TG6). the potential applications are identified as well, which require or take advantages of their standard and their specific needs[9] [10].

The communication systems are emerged by the WBANs and deployed in, on or around human body. it is known to adopt star topology with several end nodes and one coordinator, as showed in Fig. 1(a). WBAN can sense the data in different end nodes. Such data are; physical data from accelerometer and gyrometer, or the physiological data such as electrocardiogram (ECG), electroencephalograph (EEG) and electromyography (EMG). These data then transmitted to the coordinator through respective wireless links. Several attempts has been done to solve problems inside the WBAN.

However, interaction between WBANs in hospitals and senior communities, where WBANs are densely deployed, should also be givin attention. it is obvious that the impact from other WBANs are impossible to totally ignore because of the limitation of available PHY channels and random mobility of human body. The intra-WBAN transmission is going to be interfered and transmission performance is degraded when two WBANs get close to each other and just work in the same frequency band. This could happen as a result of SINR degradation. in WBAN whose primary traffics are vital physiological signals which make the situation getting worse. the applications over WBAN require it to work continuously for days and hours, however, devices in WBAN are mostly energy-constrained. more energy consumption will be added because of packet loss and throughput degradation for certain traffic load. There is a need to solve this problem with some effective ways through the future researches. Some issues have been studied, such as interWBAN interference in some recent published papers and
IEEE standard 802.15.6 [1] from different aspects. inter-WBAN interference can be avoided or mitigated by separating WBANs in time, frequency, Euler space or combinations of them as similar as MAC mechanism in wireless network. More researches about time sharing based solutions were proposed [1][4][5][6], in which WBANs interleave their active period through contention or negotiation . when the load in WBANs is heavy and duty cycle of WBAN is high, all of those solutions become ineffective. Schemes are showing in [11][12][13] and Channel hopping[1] are based on frequency rescheduling.

WBANs hop to new channels periodically[1], after channel assessment [12], or previously by predicting potential collision[13]. In frequency constrained environment, reuse of physical channel makes it difficult to ignore co-channel interference among WBANs. To cope with co-channel interference, decentralized link adaptation schemes are proposed in [14][15], in which modulation parameters, data rate and duty cycle can be adjusted linearly according to received SINR. However, these methods do not exploit the interference patterns among WBANs.

In this work and for first time we are presenting decentralized spectrum exchanging based between unlicensed users and licensed users with power allocation method. The contribution of this work are summarized as follows: We develop a decentralized non-cooperative spectrum exchanging game (DCSEG) for WBAN, which make sensors and license users exchange their spectrum to improve the data rate of the WBSN users. Then, we found cooperative optimal power which satisfy the WBSN need.

The rest of the paper is organized as follows: In Section 2, the traditional and proposed architctures is described. In Section 3, the utility function is designed. In Section 4, Nash equilibrium validation and power allocation are analyzed. In Section 5, the numerical analysis results are presented. Finally, the conclusions is presented in section 6.

II. TRADITIONAL AND PROPOSED WBAN ARCHITCTURES

A. Traditional WBSN Archticture

In the traditional WBSN network architecture, many sensors homogeneously spread over the human body to observe the important vital signs, and each of the sensor gathered and transmits the data to the CN. Thus, a WBSN is based on the single-hop star topology, all the sensors transmit their gathered data over wireless medium or HBC to the CN.
The CN, then sends their data to the next tier as explained in the previously.

B. Game theory-based Architctures

In this work, we consider architecture that is shown in the figure 1. In the shown figure, we assume the WBANs nodes are co-located within same local area, where the WBANs sensors (WS) transmits to its Coordinator node (CN), and in the same frequency band, K cognitive D2D users (CDUs)would like to exploit unlicensed spectrum of the WBAN to transmit their own signals.

In this work, the CN needs to find any appropriate relay set from the all CDUs to cooperatively fulfil it transmission as shown in the figure 1 while the CDUs have their own transmission requirements, as such communication scenario can be divided into three phases: the first phase sensors that gathered the data from the human body broadcast their data to the CDUs over unlicensed spectrum at the time slot $1-\varphi$, then at second phase the CDUs retransmit what received from the WS to the CN at the time slot $0.5\ \varphi$, finally and at last phase the CDUs transmit their own data at the time slot $0.5\ \varphi$ and over TDMA. Here, the value of the φ is decided by the CDUs and WS.

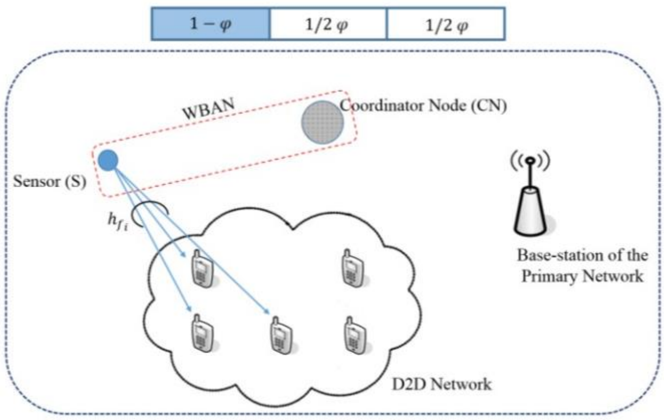

Figure 1-(a): first phase transmission, communication between WBAN sensor and D2D user.

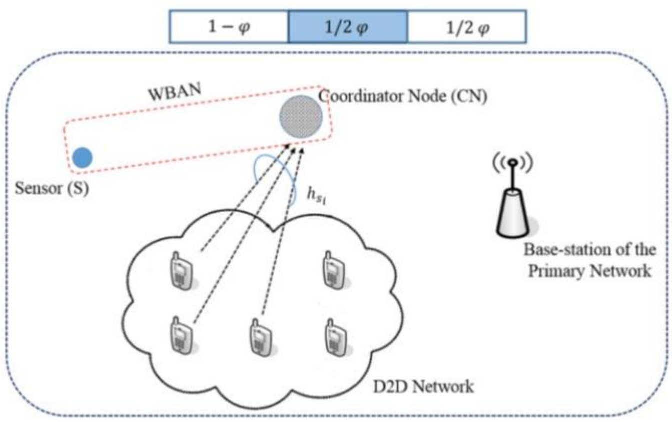

Figure 1-(b) : second phase transmission, communication between D2D user and CN.

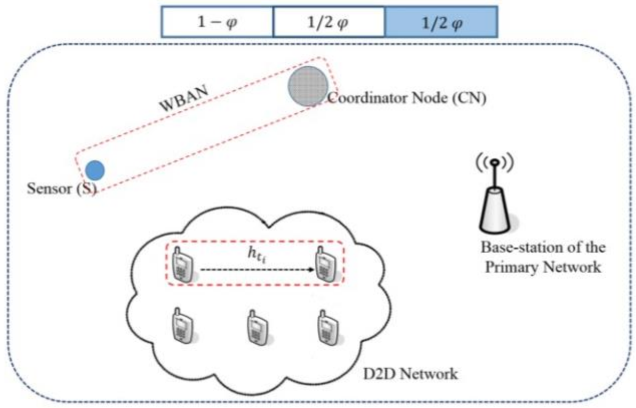

Figure 1-(c) : second phase transmission, communication between D2D users.

Fig.1. the proposed architctures is described

III. Formulation of the Utility Function

In this section, the utility function of the proposed architctures is designed and formulated. Our goal is to maximize the capacity (data rate) of both WS and CDUs. The utility function of the WS is define as

$$U_{cn} = \mu\, R_{cn}\,(1 - 0.5\varphi) \qquad (1)$$

in which, μ is the profit per data unit sent to CN, R_{cn} is derived in (6). However, for the CDUs the benefit that can be achieved is utilizing unlicensed spectrum of WBAN for sending their own data on the cost of the power which make the utility function comprised from two components: benefit and cost, thus the utility function can be defined as

$$U^{i}_{CDU} = \underbrace{\mu_1\, R_{cdu}\, t^{i}_{cdu}}_{\text{benfit}} - \underbrace{0.5\,\mu_2\, P_s\, \varphi}_{\text{cost}} \qquad (2)$$

in which, μ_1 and μ_2 are equivalent benefit data sent to the CN and cost per power consumed in the helping of the CN, R_{cdu} is the transmission rate of the CDU network and P_s is the transmission power from the CDU user to the WBAN CN (second phase transmission power). t_{cdu} is the access time for each CDU and it expressed as

$$t^{i}_{cdu} = \frac{1}{c}\, e^{-CI} P_s\, h_f\, h_s \qquad (3)$$

in which, c is the price of the time for leasing the spectrum to CDU by WS and it is determined by WS users, CI is the criticality index and it is express as [16]

$$CI = 1 - \left|\frac{\xi_{min} - \xi_{max}}{\xi_{max}}\right| \qquad (4)$$

In which $|.|$ absolute notation, the ξ_{max} is the maximu m critical data index and it equal to 7, ξ_{min} is the minimum critical data index and it is vary between 0 to 7. Therefore, CI is vary between 0 to 1. Where, ξ_{min} is depend on the gathered data from the human body, if the data is critical, then ξ_{min} is high, and vice versa. Table II shows the probability of the critical data index with a different value of ξ_{min} . To this end, R_{cn} for amplify-and-forward cooperative communication are express as

$$R_{cn} = \log_2\, \log_2\left(1 + \frac{P_f\, h_{f_i}}{P_f\, h_{f_i}\, P_s\, h_s + 1}\right) \qquad (5)$$

And the R_{cdu} is given as

$$R_{cdu} = \log_2(1 + P_t\, h_t), \qquad (6)$$

in which, P_f and P_t are the transmission power of the first and third phase, h_{fi} and h_s are the link of the first and the second phase.

IV. Nash Equilibrium Validation and Optimum Power Allocation

For a price c and the determined helper (i.e., CDU) set D, and based on the utility described previously, each CDU must to use part of power to assist WS convey data. For WS, an optimized cooperative-power for selected helper set must be determine to improve its utility. Then for CDU, its utility is related to the cooperative-power. Generally, here the game is indicated as $\mathcal{G} = \{D, \{P_i\}, \{U^{i}_{cdu}\}\}$, where D is the candidate node set, P_i is the cooperative power of CDU_i, U^{i}_{CDU} is the utility of CDU_i. Each $CDU_i \in D$ must select its power within the strategy space $P = [Pi]\ i \in D$ to maximize its utility $U^{i}_{CDU}(Pi, P - i)$.

Proposition 1 An Nash equilibrium exists in game $\mathcal{G} = \{D, \{P_i\}, \{U^{i}_{cdu}\}\}$,. If for all $CDU_i \in D$:

- P_i is a non-empty, convex, and compact subset of some Euclidean space R^K.
- U^{i}_{cdu} (P) is continuous in power domain P and concave in P_i.

Proof Proposition: For first condition, the $P = [Pi]\ i \in D$ is a non-empty, convex and compact subset of the Euclidean space R^K. Hence, first condition of NE is validate.

For second condition, we took second-order derivative for the $U^{i}_{CDU}$with respect to Pi to prove its concavity. First of all, we substitute the Pi and $0.5\,\varphi$ in equation (9), and therefore, they are written as

$$Pi = \frac{c\, t^{i\ f_i}_{cdu}}{e^{-CI}\, h\ \ h_s}, \qquad (7)$$

and,

$$\varphi = 2\left(t^{i}_{cdu} + \sum_{j \in D, j \neq i} t^{j}_{cdu}\right) \qquad (8)$$

Then, we can re -write the (9) as:

$$U^{i}_{CDU} = \left(\frac{1}{c}\, e^{-CI}\, h_{f_i}\, h_s\, P_i\,(\mu_1\, R_{cdu} - \mu_2\, P_i)\right) - \frac{\mu_2\, P_i}{c} \sum_{j \in D, j \neq i} (1 - e^{-CI})\ h_{f_i}\, h_s\, P_j \quad (9)$$

We take first derivative with respect to P_i, then, the (13) written as

$$\frac{d\, U^{i}_{CDU}}{d\, P_i} = \frac{e^{-CI}}{c}\left(h_{f_i}\, h_s\ \ (\mu_1 R_{cdu} - 2\,\mu_2\, P_i) - \mu_2 \sum_{j \in D, j \neq i} h_{f_i}\, h_s\, P_j\right) \qquad (10)$$

and second derivative for the (14), we obtain the result as

$$\frac{d^2\, U^{i}_{CDU}}{d\, P_i^2} = -\,\frac{2}{c}\,\mu_2\, e^{-CI}\ \ h_{f_i}\, h_s \qquad (11)$$

The result obtain in (11) is less than '0' with respect to P_i which mean the $U^{i}_{CDU}(P_i)$ is convex in P_i.

Proposition 2 the non-cooperative game has unique equilibrium

Proof Proposition first and According to proposition 1, we know that at least a Nash equilibrium denoted $r(P)$ exists in the non-cooperative power game, where $r(P)$ is the best response. The best response can be expressed as

$$r(P) \cong P_i^* = \frac{\mu_1 \beta_{CDU}}{2\mu_2} - \frac{\sum_{j\in D, j\neq i} h_{f_i} h_s P_j}{2 h_{f_i} h_s} \quad (12)$$

Where, P_i^* is the optimal non -cooperative game of the cooperative communication. First the best-response access power P_i^* is positive of course so $r(P) > 0$. Then, the bestresponse power function is monotonous. And finally, the $\mu r(P) - r(\mu P) > 0$, which is obtained as

$$\mu r(P) - r(\mu P) = \mu \left(\frac{\mu_1 R_{cdu}}{2\mu_2} - \frac{\sum_{j\in D, j\neq i} h_{f_i} h_s P_j}{2 h_{f_i} h_s} \right) - \left(\frac{\mu_1 R_{cdu}}{2\mu_2} - \frac{\sum_{j\in D, j\neq i} h_{f_i} h_s P_j}{2 h_{f_i} h_s} \right) \quad (13)$$

then,

$$\mu r(P) - r(\mu P) = (1-\mu)\left(\frac{\mu_1 R_{cdu}}{2\mu_2}\right) > 0 \quad (14)$$

In conclusion, the best-response correspondence power $r(P)$ is a standard function, therefore it is the unique Nash Equilibrium of the noncooperation power selection game.

V. Simulation and results

In this subsection, the performance of the proposed protocol is evaluated. In the simulation, the WBSN users and D2D users co-located in same area within radius not more than 4 meters. The WBSN users select the nearest D2D user to cooperate with and lease their spectrum.

Assume that the channel gain between any two nodes is $h = d^{-\alpha}$, where d is distance and $\alpha(= 2)$ is the path loss exponent. In the simulation, assume one time slot is 1 second. The transmission power of WBSN user is initialized as $P_f = 1\ mW$, and the transmission powers of D2D user vary from 5 to 15 dB. profit per data unit sent to CN, μ = 1000, then μ_1 and μ_2 are equivalent benefit data sent to the CN and cost per power consumed, they are 10000 and 500 respectively. The price is set to 2.5×10^{-6}.

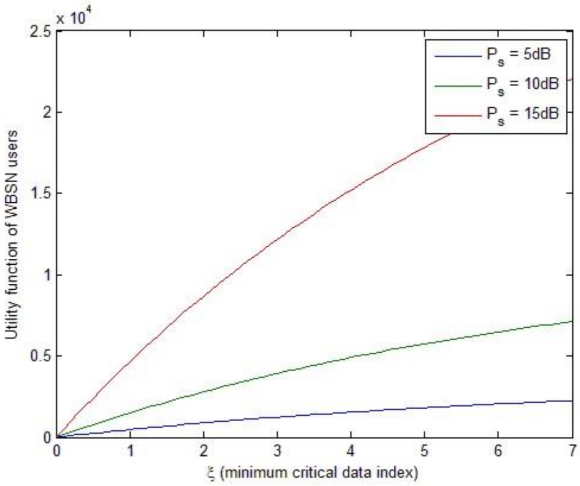

Fig.2. utility function of the WBSN user versus minimum critical data index.

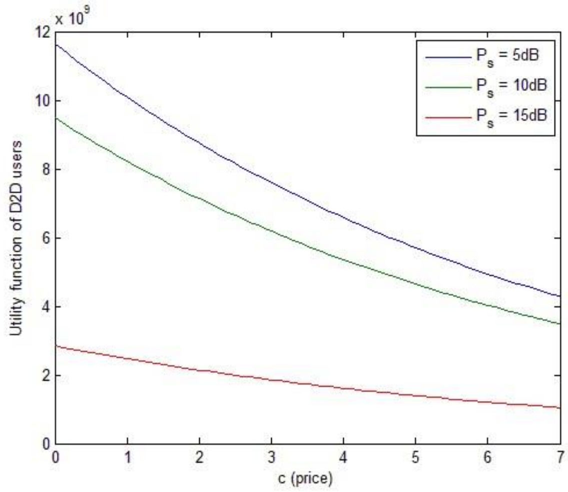

Fig.3. utility function of the D2D user versus minimum critical data index.

Figure 2 represents comparison between unity function of the WBSN users and critical data index. We can notice from the results, the utility function increase as the critical data increase that because our proposed protocol designed to allocate more attention to the critical data rather than normal data. In addition, the utility function increase as the transmission power of the D2D users increase (which is the amplify power).

The figure 3 represents comparison between the utility function of the D2D users and critical data index. The utility function reduce as the critical data index increased, because D2D users help the WBSN users on the price of the licensed spectrum. Again, the utility function reduces as the power of D2D users increase.

The figure 4 represents comparison between unity function of the WBSN users and critical data index with optimal power allocation. As we can see, the optimal power allocation has better performance compared to straight power allocation.

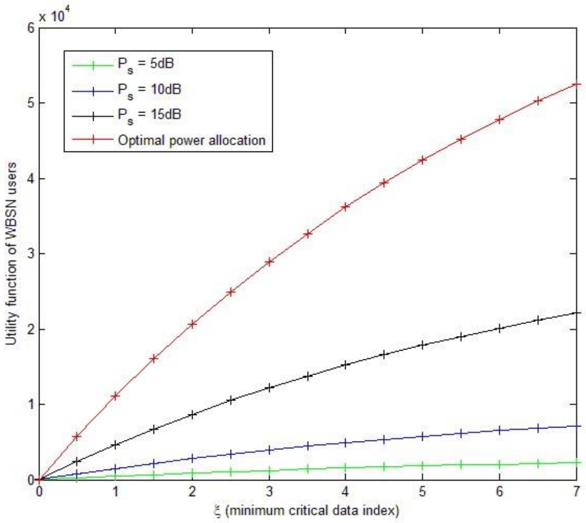

Fig.4. utility function of the WBSN user versus minimum critical data index with optimal power.

VI. Conclusion

In this paper, we proposed a non-cooperative game approach, based on utilizing a pricing-based spectrum leasing mechanism to transmit the data over several path based on non-cooperative game theory. The parameter price c is together determined by WBAN sensor and D2D users. Then, all selected D2D users used optimized powers that can be fulfilled the need of the WBSN users. Numerical results show the proposed approach improve the utility of WBSN users and their throughput.

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