Power Control of Wireless Body Area Networks Coexistence Based on Stochastic Geometry*

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ABSTRACT

Wireless Body Area Networks (WBANs) are expected to influence the traditional medical model by providing aged-care at home and health telemonitoring. In this work, we present a study of coexisting WBANs. Multi-WBANs coexistence will seriously affect the reliability of wireless communication and the network throughput because of the resource competition in a public place in many instances. In this paper, we propose a power control mechanism based on the carrier sense threshold adopting stochastic geometry. Due to the limited power supply, the transmission power value should be as small as possible based on the quality of received signal guaranteed. We derive the minimum transmission power under the many networks distribution and the carrier sense threshold.

CCS CONCEPTS

•Wireless and Mobile Communications

KEYWORDS

WBANs, stochastic geometry, CSMA/CA, power control, guard zone, throughput, success probability

Mobimedia 2017, July 13-14, Chongqing, People's Republic of China

as heartbeats, blood sugar and Electrocardio (ECG) can be monitored from a specific location using many lightweight wearable sensors [3,4]. Due to the special scenarios of the human body, it is very stringent application requirements in terms of transmission reliability, energy consumption or throughput .

WBANs have a large role in facilitating the development of medical monitoring and motion detection. Currently, most of the researches concentrate in singe network, but very few about multi-WBANs coexistence. Dynamic topology changes of WBANs are also different from other wireless networks because of the special nature of human movement. Coexisting WBANs occurs when many people wearing wireless body sensor nodes coexist in one place. WBANs coexistence can lead to network resource competition, conflicts and interference [3]. Coexisting WBANs obviously affects energy consumption, network reliability or resulting to data loss, even a serious threat to the monitors' life. Therefore, WBANs coexisting is a very challenging problem [5]. The interference is the main performance-limiting factors in wireless coexisting networks as well as increased power consumption and transmission latencies, and therefore it is ctucial to mitigated [6].

Our contributions are summarized as follows: this paper presents a new joint power control mechanism based on carrier sense threshold in order to reduce the collision or completion in coexisting WBANs according to networks distribution. We optimize the transmission power which depends on the carrier sense threshold and the density of WBANs distribution.

2 SYSTEM MODEL

In order to provide an accurate and analytically convenient assumption for the node distribution, we model multi-WBANs as a stationary Poisson cluster process coexisting in the $\mathbb{R}^2$ Euclidean space such as in Fig.. 1. Each WBAN is composed of the coordinator node (CN) and terminal nodes (TNs). All TNs have assumed that they have exactly the same performance and parameters. According to the IEEE 802.15.4 standard, we consider a TN in each WBAN sending data successfully [7]. Accordingly, each WBAN can be considered as a terminal node (TN) and a CN. In particular, denote r as the distance between node TN and CN. All the active TNs in multi-WBANs are taken as a Poisson Point Process model (PPP) with density λ_p. The target domain of area is denoted as G. Denoting n is the number of TNs in G. So the numbers of TNs in the domain G is given by $\mathbb{P}(\phi(G)=\mathrm{n})=\frac{(\lambda_p|G|)^n e^{-\lambda_p|G|}}{n!}$, where $|G|$ denotes the area of the set G [8].

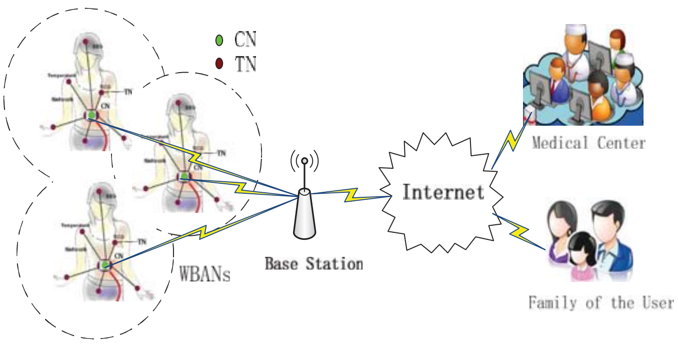

Figure 1: WBANs coexistence model

This PPP model is expressed as $\phi=\{(x_i,m_i,p_i)\}$, where

(1) $\{x_i\}$ denotes the locations of the transmit points, ϕ is always assumed Poisson with positive and finite intensity.

(2) $\{m_i\}$ are expressed as marks, uniformly distributed on [0,1] [9].

(3) The transmission power value is given by $\{p_i\}$.

We consider that signal attenuation follows the log-distance path model and ignore shadowing at a path loss exponent $\alpha(\alpha>2)$. Therefore, the received power P_r at a distance r from TN to CN is given by $P_t h r^{-\alpha}$, where the random variable h obeys an exponential distribution with mean $1/\mu$, which can be denoted as $h\sim\exp(\mu)$.

3 JOINT CARRIER SENSE THRESHOLD AND POWER CONTROL

In this section, we try to obtain appropriate carrier sense range that can reduce the collision or completion in coexisting WBANs in order to solve this problem, a new mechanism called mean distance carrier sense (MDCS) is proposed according to networks distribution. It is applicable for multi-networks or many wireless nodes. The proposed design is performed in the following three steps. First, we derive the mean distance of nodes through performance of multi-WBANs analysis. Second, we obtain the expression of mean number of TNs in the contain domain at the same channel. Third, we optimize the carrier sensing range according to the above described expression.

In the coexisting WBANs, the distribution of wireless nodes is stochastic and cannot be calculated due to the mobility of people. The aim of this power control mechanism is to find the minimum transmission power value to ensure received signal properly decoded [10]. This value is not fixed owing to the interference of the adjacent nodes. Under this circumstances, there exists a suitable carrier sense threshold γ. The transmission power value relies heavily on the WBANs density λ_p or the carrier sense threshold γ. Ideally, the cross domain of carrier sense range of every transmit node is comparatively small under the success probability limited. The best condition is the number of nodes is one in a radius of carrier sense range. But this is not quite the case. Sometimes there are several nodes in a circle due to the nodes random distribution. On the basis of the above analysis, we propose the joint power control strategy and carrier sense threshold to discover the relationship of transmission power, the networks density and carrier sense threshold. The purpose of this method is to decrease the total power consumption of the networks, but also overcome the interference of coexisting WBANs.

First, the probability of distribution function (PDF) of carrier sense range is derived according to the above analysis. We may take the node A to be at the origin O owing to the properties of the stochastic geometry. The radius of circular of M is expressed by carrier sense range R_{CS} . The complementary cumulative distribution function (CCDF) of the radius similar circle M is expressed as

$$\mathbb{P}(R_{CS} \geq r) = \mathbb{P}(\phi(M)=1) = \exp(-\lambda_p |M|)\frac{\lambda_p |M|}{1!}$$
$$= \lambda_p \pi r^2 \exp(-\lambda_p \pi r^2) \quad (1)$$

So the PDF of R_{CS} equals

$$f_{R_{CS}}(r) = 2\lambda_p \pi r(\lambda_p \pi r^2 - 1)\exp(-\lambda_p \pi r^2) \cdot \quad (2)$$

The maximum transmission range should be smaller than $(\frac{P_t}{\gamma})^{\frac{1}{\alpha}}$ between a source to destination pair nodes according to the channel model. The distribution of the other TNs is $f_{R_{CS}}(r)$ in (2), and the $P_t = P_{th}(d_0)^{\alpha}$ ($0 < P_t < P_{max}$). Therefore, the PDF of transmission power is given by the following Lemma in the light of the compound function calculation.

Lemma 1. In a coexisting WBANs with joint carrier sense threshold and minimum power control, for a carrier sense threshold γ and density distribution λ_p , the PDF of the transmission power of a generic active TN is expressed by

$$f(P) = \frac{2\lambda_p \pi (P)^{\frac{2}{\alpha}-1}}{\alpha (P_{th})^{\frac{2}{\alpha}}(1-\lambda_p \pi (\frac{P_{max}}{P_{th}})^{\frac{2}{\alpha}} \exp(-\lambda_p \pi (\frac{P_{max}}{P_{th}})^{\frac{2}{\alpha}}))} \quad (3)$$
$$[\lambda_p \pi (\frac{P}{P_{th}})^{\frac{2}{\alpha}} - 1]\exp(-\lambda_p \pi (\frac{P}{P_{th}})^{\frac{2}{\alpha}}) \quad 0 < P < P_{max}$$

Proof: See **Appendix A**.

4 PERFORMANCE EVALUATION

For the numerical evaluation, a WBAN is formed by a CN and a TN. The initial maximum transmission distance between the CN and TN in a WBAN is set to 5 meter. The radio settings are configured according to the IEEE 802.15.4 standard.

The purpose of this section is to verify the proposed algorithm through MATLAB simulation. PPP model has been adopted for the operation of coexisting IEEE 802.15.4-based WBANs. We simulate the operation of WBANs in a random situation with different density of coexisting WBANs and thinning the PPP model through adding a hard-core size in each receiving node. The simulation is repeated 10000 times.

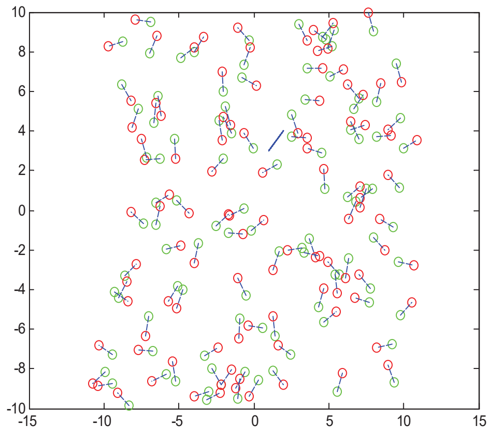

Figure 2: PPP model (Red dots represent the CNs while the green dots represent the TNs.)

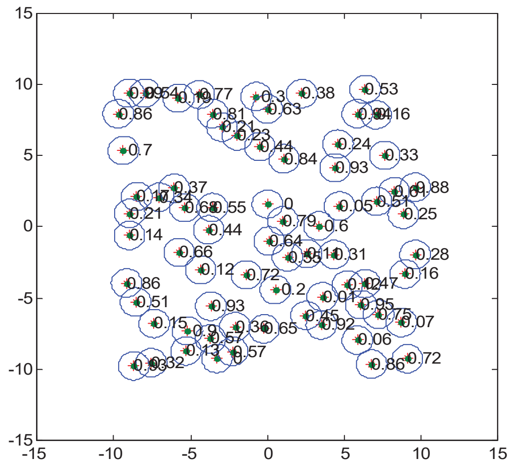

Figure 3: HCPP model

The valid transmission scope will change with varying of the carrier sensing threshold. The contain domain is the carrier sense range of each transmitter. Many transmission nodes have been scattered in the 20m*20m area in the light of a certain density. To simplify the analysis, there is only one node sending data successfully at a time in each WBAN according to the CSMA standard, such as Fig. 2. The red dots represent the TNs while the green dots represent CNs in Fig. 2. Fig. 3 is that the Matern hard core point processes (HCPP) model with the hard-core value 1m.

The HCPP model expresses the patterns that only the TNs with minimal mark is left in the threshold of the hard core. The center of circle shows a TN while the decimal is the value of mark. The radius of circle is the size of hard-core.

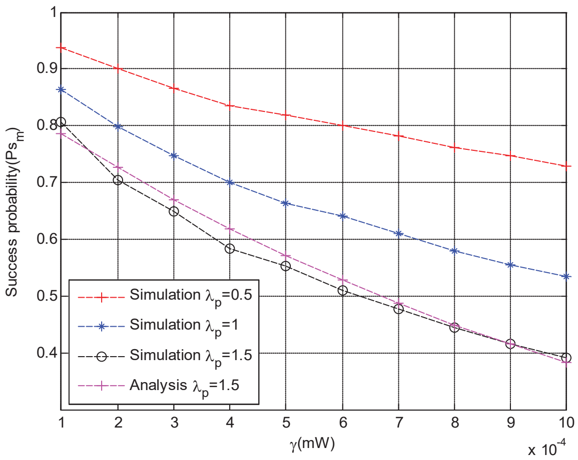

Figure 4: The success probability of MDCR mechanism with the carrier sensing threshold γ

Fig. 4 shows that the relationship between carrier sensing threshold value γ and transmission success rate p_{s_M}. The data transmission success probability of MDCS descends quickly with the increased of the carrier sensing threshold. This indicates that the interference level and the outage probability rasie with the carrier sense range decreasing.

Fig. 5 describes the data transmission success probability of MDCS mechanism, PPP model and HCPP model with the different density λ_p. The performance of proposed MDCS mechanism and HCPP model are obviously superior to the PPP model.

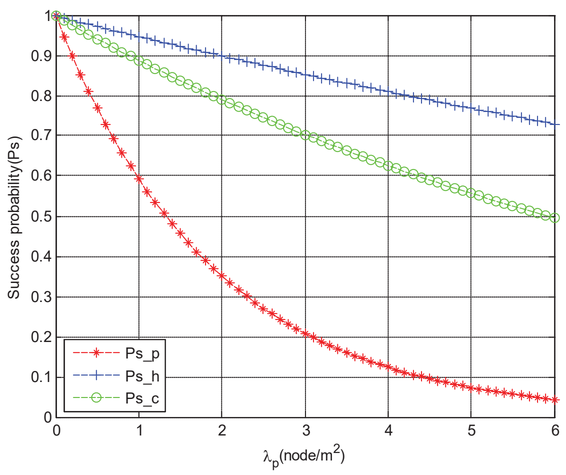

Figure 5: The success probability comparison of three mechanisms

5 CONCLUSION

In this paper, a new power control mechanism is proposed according to the considered carrier sense threshold. The throughput is guaranteed through this strategy and HCPP model ways. A transmitter can adjust its power level based on the channel attenuation and the interference of surrounding nodes to its target receiver. The results have proved that the success probability is largely dependent on the parameters: networks distribution density (λ_p), the transmission power of nodes (P_t) and the carrier sense threshold (γ). We derive an approximate expression for success probability and the throughput.

Appendix A:

We can derive the minimum transmission power as possible to decrease interference to the surrounding TNs. The transmission power of TNs is given by $P_t = \gamma r_0^{\alpha}$, where the r_0 is the distance of source to destination pair. The carrier sense range distribution of TNs is

$f_{R_{CS}}(\mathrm{r}) = 2\lambda_p\pi r(\lambda_p\pi \mathrm{r}^2 - 1)\exp(-\lambda_p\pi r^2)$. Therefore, the PDF of transmission power can be written as

$$g(\mathrm{P})\underset{=}{(a)} 2\lambda_p\pi(\frac{P}{P_{th}})^{\frac{1}{\alpha}}[\lambda_p\pi(\frac{P}{P_{th}})^{\frac{2}{\alpha}}-1]\exp(-\lambda_p\pi(\frac{P}{P_{th}})^{\frac{2}{\alpha}})\frac{d((\frac{P}{P_{th}})^{\frac{1}{\alpha}})}{d(r)}$$

$$=2\lambda_p\pi(\frac{P}{P_{th}})^{\frac{1}{\alpha}}[\lambda_p\pi(\frac{P}{P_{th}})^{\frac{2}{\alpha}}-1]\exp(-\lambda_p\pi(\frac{P}{P_{th}})^{\frac{2}{\alpha}})\frac{1}{\alpha}(\frac{P}{P_{th}})^{\frac{1}{\alpha}-1}$$

$$=\frac{2\lambda_p\pi(\mathrm{P})^{\frac{2}{\alpha}-1}}{\alpha(P_{th})^{\frac{2}{\alpha}}}[\lambda_p\pi(\frac{P}{P_{th}})^{\frac{2}{\alpha}}-1]\exp(-\lambda_p\pi(\frac{P}{P_{th}})^{\frac{2}{\alpha}})$$

$\underline{\underline{(a)}}$ is derived by the calculation of PDF of composite function.

$$\int_0^{P_{\max}} g(x)dx$$

$$=\int_0^{P_{\max}}\frac{2\lambda_p\pi(x)^{\frac{2}{\alpha}-1}}{\alpha(P_{th})^{\frac{2}{\alpha}}}[\lambda_p\pi(\frac{x}{P_{th}})^{\frac{2}{\alpha}}-1]\exp(-\lambda_p\pi(\frac{x}{P_{th}})^{\frac{2}{\alpha}})dx$$

$$=1-\lambda_p\pi(\frac{P_{\max}}{P_{th}})^{\frac{2}{\alpha}}\exp(-\lambda_p\pi(\frac{P_{\max}}{P_{th}})^{\frac{2}{\alpha}})$$

$$f(P)\underline{\underline{(b)}}\frac{g(\mathrm{P})}{\int_0^{P_{\max}} g(x)dx}$$

$$=\frac{2\lambda_p\pi(\mathrm{P})^{\frac{2}{\alpha}-1}}{\alpha(P_{th})^{\frac{2}{\alpha}}(1-\lambda_p\pi(\frac{P_{\max}}{P_{th}})^{\frac{2}{\alpha}}\exp(-\lambda_p\pi(\frac{P_{\max}}{P_{th}})^{\frac{2}{\alpha}}))}[\lambda_p\pi(\frac{P}{P_{th}})^{\frac{2}{\alpha}}-1]\exp(-\lambda_p\pi(\frac{P}{P_{th}})^{\frac{2}{\alpha}}) \quad 0<P<P_{\max}$$

$\underline{\underline{(b)}}$ is normalized owing to the range value of transmission power.

ACKNOWLEDGMENTS

This work is supported by the National Natural Science Foundation of China under Grant No. 61401256 and by the Innovation Program of the Shandong Academy of Sciences Grant No.[2012]153.

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