A New Stochastic Geometry Model of Coexistence of Wireless Body Sensor Networks

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Abstract. Stochastic geometry, in particular Poisson point process theory, has been widely used in the last decade to provide models and methods to analyze wireless networks. It is a branch of mathematics which deals with the study of random point processes. There are various models for point processes, typically based on but going beyond the classic homogeneous Poisson point process. Poisson point process cannot be used to model the spatial distribution of the simultaneously active transmitters. A novel framework has been presented for modeling the intensity of simultaneous active transmitters of a random carrier sense multiple access wireless sensor network. This thinning rule uses a second-neighbors distance-dependent method, which controls too many nodes deleted of points close together.

1 Introduction

WBSNs enable wireless communications between several miniaturized body sensors and a single coordinator worn on the human body. WBSNs offer many promising new applications in the area of remote health monitoring systems to measure specified physiological data and also provide location-based information. Since a WBSNs provide remote and continuous medical monitoring for patients without constraining their movements, it plays a crucial role in next generation healthcare applications [1-2].

WBSNs for health monitoring systems are required to meet stringent performance demands regarding the tradeoff between reliability, latency, and power efficiency. WBSNs feature limited range and bandwidth and they are prone to interference. These modes incur issues regarding the coexistence of multiple WBANs. There is often a group of BSNs together to happen in hospitals for patients and staff or for the elderly at nursing homes [3]. In many cases, several WBSNs coexist in a small area, resulting in very strong inter-BAN interference, which seriously disturbs intra-BAN communications [4].

In this paper, we use stochastic geometry to analyze the coexistence of IEEE802.15.4-based WBSNs Stochastic geometry is an established branch of mathematics that studies uncertainty in geometric structures. The density of effective points in model is a sufficient parameter to describe the network performance. However, The HCPP model still suffers from the underestimation problem. So we proposed a PCMP model to mitigate this problem.

We propose a new thinning method of CSMA network to mitigate the node intensity underestimation problem of HCPP model. We put forward a modified Poisson cluster and marked process (PCMP) to adapt to this network coexistence The PCMP model is generalized for CSMA protocol's network.

Define:

Contention domain: node y is in the contention domain of node x if the power received by x from y is above some detection threshold.

Neighbors: the neighbors of a node are the nodes in its contention domain.

Second Neighbors: the neighbors of a origin node's neighbors node.

The rest of the paper is organized as follows: Section 2 introduces the related work. Section 3 proposes and describes the system model in detail. In Section 4, thinning theory and stochastic geometry are used to investigate the CSMA-based wireless sensor networks coexistence. Section 5 illustrates and analyzes numerical results. We conclude our work in Section 6.

2 Related work

Since the Poisson Point Process (PPP) is highly tractable, it is frequently used to model a variety of networks, such as cellular networks, mobile ad hoc networks, cognitive radio networks and wireless sensor networks[5-6]. In [7], the authors assume the star topology network's transmission nodes to be uniformly distributed according to a PPP. this paper stands in the precise consideration of CSMA algorithms, considering the collision, the success transmit probability and interference in the same network. The matern hard core are often used to model concurrent transmitters in CSMA networks [8-9]. Hesham EISawy et al. [10] adopt the Poisson cluster process to obtain the minimum required number of channels of the coexisting IEEE 802.15.4 networks, but the underestimation problem is not fully resolved.

3 System model

The carrier sense multiple access with collision avoidance (CSMA-CA) is widely employed in wireless networking due to its simplicity and performance efficiency [11].

CSMA create exclusion zones to protect scheduled transmissions that nodes which are close by never transmit simultaneously. CSMA-type MACs essentially create a guard zone around the receiver [12]. The traditional homogeneous PPP doesn't suit to this coexisting IEEE 802.15.4 networks, so we proposed PCMP model.

We consider WBSNs, each contains one receiver(CN: the cord node) and N transmitters(SN: sensor node). In our proposed model, the CN is placed at center of the human body. Some SN are deployed on a human body, forming a star topology with the CN such as Figure 1. Each SN has equal power and computation capabilities.

Fig. 1. System model.

The WBSN's locations are modeled as a stationary and isotropic Poisson cluster process (PCMP) coexisting in the R^2 Euclidean space. The cluster process consists of the cluster centers (CNs) and cluster members (SN). The CNs spatial distribution model is a PPP with intensity λ_{ppp} . For the Poisson cluster process, each cluster member is uniformly distributed around the cluster center.

This PCMP is denoted by $\phi = \{x_i, m_i, p_i\}$, where

$\{x_i\}$ denote the locations of the transmit points, is always assumed Poisson with positive and finite intensity λ_{ppp} .

$\{m_i\}$ are marks, uniformly distributed on $[0,1]$.

$\{p_i\}$ denote the transmit power by node i .

We denote target domain of area as M . Denoting by K the number of CNs in M . K is Poisson distributed with mean $\lambda_{ppp} M$ and probability mass function (pmf). M is the standard Lebesgue measure of M . So the numbers of CN in the domain A is:

$$P(k=n) = \frac{(\lambda_{ppp} M)^k e^{-\lambda_{ppp} M}}{n!}$$

Define the contention domain:

$$N_x = \{(x_i, m_i, p_i) \in \phi : p_i h \mid |x_i - x_j|^{-\alpha} \geq \beta\}$$

The medium access indicators $e_i = 1(\Delta x_i \in N_x, x_i < x_j)$

The lower the carrier-sensing threshold β the higher the sensitivity of each transmitter to other transmissions occurring in the spatial domain, which increases the distances between simultaneously active transmitters and decreases the mutual interference at the expense of decreasing the spatial frequency reuse [13].

4 Thinning method

To consider a realistic medium-access control (MAC) layer algorithm, successful signal reception is based on the protocol model, and nodes employ carrier-sense multiple access [14]. One of the best choices for such scenarios is to use pure carrier sense multiple access (CSMA), which only incorporates channel sensing. In the CSMA protocol, every communication entity first senses the ongoing transmission in the channel and then determines when to start transmitting [15]. A node which wants to access the shared wireless medium senses its occupation and refrains from transmitting if the channel is already locally occupied.

Throughout this paper, we will say that the transmitter x_i is older than the transmitter x_j (or equivalently x_j is younger than x_i) to denote that $m_i > m_j$. The hard core point process (HCPP) accounts only for the points having the lowest mark in their contention domains [16].

The classical HCPP leads to the following scenario: node x_1 is not retained because of it detects its neighbors x_2 ; moreover node x_2 in turn is not retained because it detects its neighbor x_3 ($m_1 > m_2 > m_3$), such as the nodes with marks 0.9, 0.3, 0.2 in Figure 2. Consequently, in the Matern CSMA model neither x_1 nor x_2 is retained. But if x_3 is not the neighbor of x_1 , and if x_3 does not detect any of its neighbors then a more reasonable MAC would allow x_1 and x_3 to transmit simultaneously [17]. Such phenomena underestimate the density of the actual running network. Node is retained rules:

- (1) $\{m_i < m_j \mid m_i, m_j \in B_{x_i}(\beta)\}$
- (2) $\{m_j < m_d < m_l \mid m_d, m_l \in B_{x_j}(\beta) \setminus x_j\}$

Fig. 2. The second neighbour node.

The shaded area:

$$A(d) = \pi R^2 - 2R^2 \arccos\left(\frac{d}{2R}\right) + \frac{d}{2} \sqrt{4d^2 - R^2}$$

According to the distance properties of a PPP:

$$0 < d < R$$

$$E(d) = \frac{1}{2\sqrt{\lambda_{ppp}}}$$

$$E(A(d)) = \pi R^2 - 2R^2 \arccos\left(\frac{E(d)}{2R}\right) + \frac{E(d)}{2} \sqrt{4E(d)^2 - R^2}$$

The probability of x_k is the lowest mark in the $A(d)$:

$$P(A) = P\{m_k < m_u, m_u \in (B_{x_j}(\beta) - B_{x_i}(\beta)) \setminus x_j\}$$

The probability of the nodes retained:

$$\begin{aligned}
 p &= \sum_{n=0}^{\infty} \frac{1}{n+1} \frac{\wedge_{B_{x_i}}^n e^{-\wedge_{B_{x_i}}}}{n!} \sum_{m=0}^{\infty} \frac{1}{m+1} \frac{\wedge_{A(d)}^m e^{-\wedge_{A(d)}}}{m!} \\
 &= \frac{1-e^{-F}}{F} \frac{1-e^{-H}}{H} \\
 p_{PCMP} &= \frac{1-e^{-F}}{F} \left(1 + \frac{1-e^{-H}}{H}\right) \\
 \lambda_{PCMP} &= \lambda_{PPP} p_{PCMP} \\
 &= \lambda_{PPP} \frac{1-e^{-F}}{F} \left(1 + \frac{1-e^{-H}}{H}\right)
 \end{aligned}$$

5 Simulation results

We have distributed many transmission nodes in the 20m*20m area according to certain density. Set the contain domain R around the origin. If the closet node's distance is less than a certain value, the node with the smallest mark is retained.

Fig. 3. PPP model and PCMP model.

Fig. 4. The retained nodes of HCPP model and PCMP model.

Figure 3 compare the classical hard core point process and the PCMP via Monte Carlo simulations using Matlab to verify the accuracy of mode. We distributed many transmitter nodes in the 100 meters of area according to certain density. Set the contain domain is 2 m. If the closet node's distance less than 2, the node with the smallest mark is retained. The underestimation problem of HCPP model lead to the many of nodes is unselected, so in the Figure 4 the number of remaining nodes in PCMP model is much more than the HCPP model. Their number of selected node is the same in the low density because the intersect probability of contain domain is very small.

6 Conclusion

PCMP is derived by applying a specific thinning rule to a homogeneous Poisson point process in $\mathbb{R}^2$. In the following, the way of thinning a Poisson point process in order to obtain a moderate point process. The proposed model will be useful for capturing the intensity of simultaneously active nodes in a random CSMA wireless sensor networks.

APPENDIX A

$$\begin{aligned} p &= \sum_{n=0}^{\infty} \frac{1}{n+1} p(|B_{x_i}(R) \setminus x_i| = n) \sum_{m=1}^{\infty} \frac{1}{m+1} p(|A(d)| = m) \\ &= \left(\frac{e^{-F}}{F} \sum_{n=0}^{\infty} \frac{F^{n+1}}{(n+1)!} \right) \left(\frac{e^{-H}}{H} \sum_{m=0}^{\infty} \frac{H^{m+1}}{(m+1)!} \right) \\ &= \frac{1 - e^{-F}}{F} \frac{1 - e^{-H}}{H} \end{aligned}$$

Where $F = \wedge_{B_{x_i}} = \lambda_{ppp} \pi R^2$ is the mean number of nodes in B_{x_i} , $H = \wedge_{A(d)} = \lambda_{ppp} E(A(d))$ $E(A(d))$ is the mean numbers of nodes in $E(A(d))$.

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