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Flexible Beacon Design For 60 GHz Wireless Personal Area Networks

Tunçer Baykaş

İstanbul Medipol University, Engineering Faculty, Department of Computer Engineering, 34810, İstanbul

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Abstract: In this paper we investigate the effect of different beaconing strategies for wireless personal area networks. Beacons are used by network coordinators to indicate the existence of the networks. A long beacon range protects the devices from interference of neighboring networks. Nevertheless increased protection reduces number of possible networks in an area and increases number of devices per network. We investigate the effect of the beacon range in terms of throughput in IEEE 802.15.3c based 60 GHz WPANs. Long range beacons enable %20 more, while allowing %40 less networks. throughput In addition we are suggesting a flexible beacon system which can adjust the piconet protection. In certain situations, flexible beaconing both increase the troughput of protected link and the total number of networks in the area.

60 GHz Kablosuz Kişisel Ağlar İçin Esnek Kılavuz İşaret Tasarımı

Anahtar Kelimeler
60 GHz,
Kişisel ağlar,
Girişim,
İşaret penceresi

Özet: Bu makalede farklı kılavuz işaret stratejilerinin kablosuz kişisel ağların başarımına olan etkisini incelenmiştir. Ağ koordinatörleri kılavuz işaretleri, ağın varlığını belirtmek için kullanırlar. Eğer kılavuz işaretinin menzili uzunsa, komşu ağlarda bulunan cihazlardan daha az girişim alınır. Fakat bu durum belli bir alanda sınırlı sayıda ağa izin verip ağ başına düşen cihaz sayısını arttırır. Kılavuz işaretinin ağ kapasitesine olan etkisini incelemek için IEEE 802.15.3c tabanlı 60 GHz kişisel ağları seçtik. Uzun haberleşme menzili olan kılavuzlar girişim altında olan cihazlara yaklaşık %20 daha fazla kapasite sağlamakla beraber çok daha az sayıda ağa izin vermektedir. Ayrıca bu çalışmada kablosuz ağın girişimden korunması için esnek bir kılavuz işaret sistemi önerilmiştir. Esnek kılavuz işaretleri hem girişime dayanıklılık sağlarken hem de toplam kablosuz ağ sayısını yüksek tutmaktadır.

1. Introduction

In consumer electronics, short-range, relatively low-cost and low transmit-power communication networks are called wireless personal area networks (WPANs). The term piconet identifies a group of connected WPAN devices. The range of piconets is usually in the order of meters. The total throughput of a piconet is determined by the available RF bandwidth, selected physical layer properties and multiple access methods and total number of devices. Due spectrum scarcity at lower bands, regulatory bodies such as FCC of United States [1], MIC of Japan [2] and ETSI of Europe [3] allowed overlapping bands in 60 GHz spectrum. BTK of Turkey follows ETSI.

The focus of this paper is the WPANs with central piconet controller (PNC) [4]. A PNC is responsible of sending beacons thus announcing the existence of the piconet, admitting other devices to the network and determining the communication schedule. To decrease complexity of overall system PNC's have fixed beacon ranges, as in the case of 60 GHz Single-Carrier WPANs, which is employed in IEEE's WPAN standard 802.15.3c [5,6]. Such a fixed range limits PNC's ability to control total number of devices, which may join the piconet and determine the cochannel interference (CCI) level from and towards the piconet. In the literature the effect of CCI for 60 Ghz is studied in [7,8]. In [7], the CCI is studied in outdoor environments, whereas authors in [8] focus on WPANs. Authors assume two devices interfering each other without providing detailed circumstances. In [9], authors suggested an interference mitigation technique by using additional frames. However this increases the complexity.

Therefore we are suggesting a flexible beacon range system, in which the PNC adjusts its beacon range according to the status of DEVs inside the piconet. Our system keeps the size of the piconet minimum thus allowing more piconets in a given area, while

*Corresponding author: tbaykas@medipol.edu.tr

protecting throughput between PNC and DEV. In this paper first, we will examine system design of 60 GHz WPAN. Compared to the conventional WPANs, the merit of using 60 GHz system is the large available bandwidth, which enables data rates on the order of Gbps without using multiple antennas or high level modulation schemes. Afterwards we look at the cochannel interference in 60 GHz system. We test the effect of beacon size to throughput of 60 GHz WPANs and compare it with flexible beacon design. Last section of this work is reserved for conclusions.

2. System Design

An outline of piconet that is a basic communications unit for 802.15.3c MAC is shown in Figure 1 [2]. A piconet includes one PicoNet Coordinator (PNC) and other DEVs (DEVices). PNC has a function of broadcasting beacons.

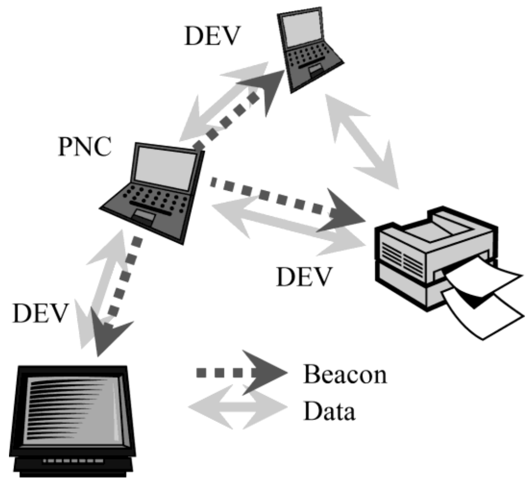

Figure 1. Outline of a piconet.

Figure 2 shows the operation of a PNC and the association of a device to the Piconet. The timing in a piconet is based on superframes. The duration between two beacon transmission is defined as the superframe duration. A superframe consists of three periods, Beacon Period (BP), Contention Access Period CAP (CAP) and optional Channel Time Allocation Period CTAP (CTAP). BP is reserved only for beacon broadcasting. CAP is used mostly for the transmission of command frames and employs CSMA (Carrier Sense Multiple Access).

3. Beacon Design

The common mode signaling (CMS) is designed for beacon and command frame communication in Single Carrier WPANs and also to avoid interference among 3 different PHYs of 802.15.3c . 802.15.3c has two other OFDM based PHYs and for coexistence between PHYs. CMS must be designed as strong enough to penetrate up to 10 m but it should be simple enough to reduce implementation complexity. Designers selected π/2 BPSK modulation with forward error coding of RS(255,239) and spreading factor of SF=64 [5].

The chip rate of CMS is 1760 Mchips/s. Resulted link budget of the CMS system can be seen in Table 1. As shown the CMS can penetrate up to 10 meters in a non line-of-sight (NLOS) environment. Although not shown the range of CMS in line-of-sight (LOS) is 33 m [10].

4. Cochannel Interference

Since multiple independent piconets in an area use the same frequency band, they generate interference to each other. In Figure 3, different colors denote different piconet areas. Triangle shows the PNC (PNC1) of the piconet in the middle of the simulation area and dot inside the square shows a DEV (Victim-DEV) belonging to that piconet. The DEV inside the circle (Int-DEV) belongs to another piconet and is very close to Victim-DEV. Any transmission from Int-DEV during CTA of Victim-DEV will decrease the quality of service for Victim-DEV. Different modulation and coding schemes have different robustness to against interference.

We consider 4 physical layer modes (PHY Mode) of 802.15.3c in this work, assuming there one interferer their robustness are shown in Figure 4. The assumption for link connection is a bit error rate of 10^{-6} as required by the 802.15.3c standard design.

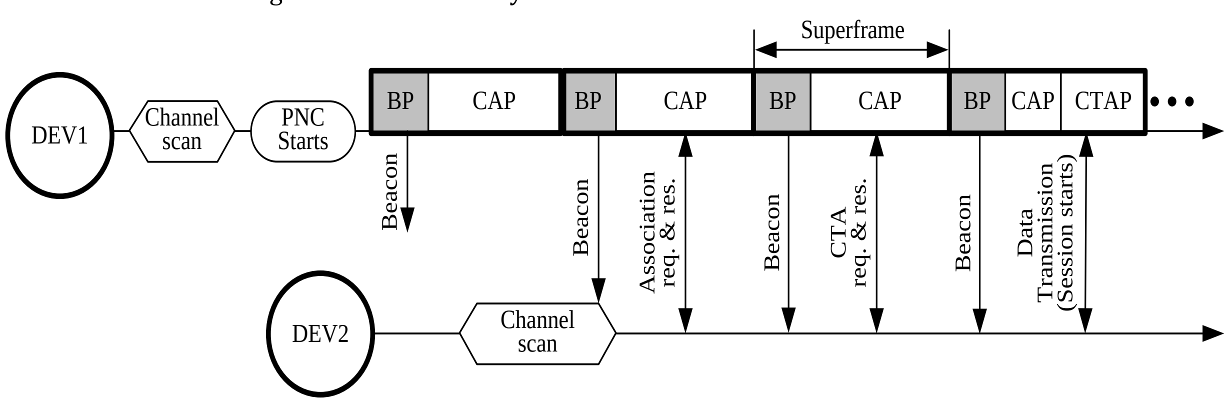

Figure 2. Timing in PNCs and the concept of superframe

All 4 modes are using RS(255,239) coding. Mode 1 use π/2 QPSK modulation has 2.88 Gbps data rate. Mode 2, 3 and 4 are using π/2 BPSK with spreading factors of 1, 2 and 4. Their corresponding data rates are 1.44 Gbps, 0.72 Gbps and 0.36 Gbps respectively. The values are obtained by first setting a cochannel interference level based on the distance and determining corresponding SNR levels of the mode. During simulation the frames are of length 2048 bytes as required by the standard. Afterwards corresponding link, interference distances are obtained. The details can be found in [10].

Table 1. Link Budget of Common Mode Signaling

Environment	NLOS
Transmitter	
Information Data Rate (Rb)	25.31Mbps
Coding Rate	0.94
Spreading factor (SF)	64
Center Frequency (GHz)	60 GHz
Bandwidth (GHz)	1.726 GHz
Tx Antenna Gain (GT)	3 dBi
Tx Average Power (PT)	10.00 dBm
Receiver	
Average Noise Power per Bit (N = -174 + 10xlog(Rb))	-100.0 dB
Rx Noise Figure Referred to the Antenna Terminal (NF)	8.0 dB
Average Noise Power per Bit (PN = N +NF)	-92.0 dB
Payload Eb/N0(S)	8.1 dB
Payload CNR	-10.2 dB
Implementation Loss (I)	1.5 dB
Rx Antenna Gain (GR)	3 dBi
Sensitivity	
Propagation Loss Index (n)	2.5
Path Loss at 1m (PL0)	68.00
Minimum Received Signal Level (Smin)	-82.3 dB
Shadow Margin (M)	5.0 dB
Rx Power Calculations	
Tolerable Path Loss PL=PT + GT + GR-PN-S-M-I-PL0	25.32 dB
Range $d=10^{(PL/10n)}$	**10.3 m**

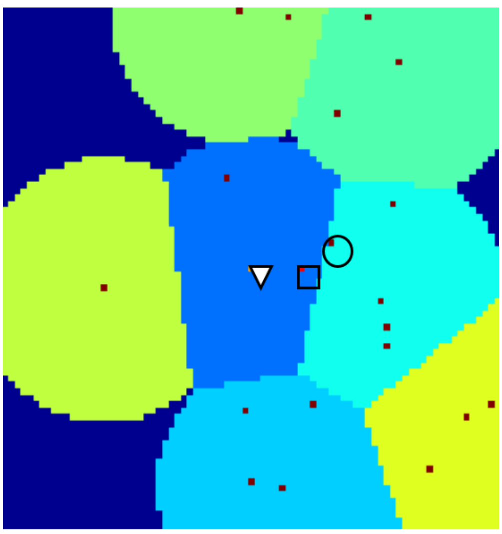

Figure 3. Simulation snapshot indicating different piconets

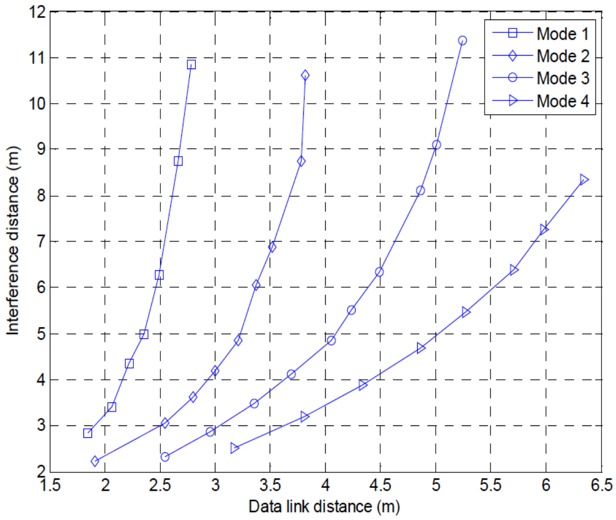

Figure 4. Data link distance versus interference distance.

5. Flexible Beaconing

As explained in previous sections 802.15.3c system the beacon range is fixed. We are proposing a flexible beaconing scheme. PNC1 starts with a normal beaconing range and after the first DEV joins the piconet. PNC1 estimates the distance of the DEV from the received SNR. According to estimation, PNC1 calculates necessary beacon range to enable highest possible data rate and adjusts PHY layer parameters to enable that range. For example if the data link is at 3 meters, the maximum data rate is 0.72 Gbps with Mode 2 according to Figure 4. Shortest tolerable interference distance is 4.1 meter; therefore a beacon longer than 7.1 meter is enough to prevent any other PNC inside the interference zone.

Examples of PHY layer parameters for adjusting the beacon range are transmit power, modulation scheme, coding scheme and spreading factor. Among those we decided to use changing the spreading factor in this work. By changing spreading sequences spreading factor of the beacon is changed and 4 beacon ranges are obtained 5.9 m (SF=16), 7.8 m (SF=32), 10.3 m (SF=64) and 13.6 m (SF=128).

6. Simulation System and Results

Multiple piconets in a large office setting in 40m by 40m area, in which the PNC1 is at the center are simulated. A Victim-DEV is located 2 to 6 meters away from the PNC1. Victim-DEV location changes in each realization. During the simulation remaining DEVs appear one by one and each DEV checks if there is a piconet to ne joined. If a DEV cannot join any piconet, DEV becomes a PNC and creates its own piconet.

For interference modeling we assume that the devices are on top of office desks. It is assumed that if a DEV receives beacons of different PNCs it selects the stronger one. After each extra user Victim-DEV adjusts its PHY mode according to the received interference level. If the interference is higher than the Victim-DEV can handle with the most robust PHY Mode (Mode 4), the connection is lost.

During the simulations we focus on two points. First, the average number of piconets, which is important since it shows total number of simultaneous transmissions in the given area. Second, the throughput of the victim receiver, since the flexible beaconing is designed to protect the Victim-receivers throughput. In each simulation, average values of 2000 realizations are obtained. In the first simulation we assume 10.3 meter beacon range, which is the range of current 802.15.3c system. As can be seen from Figure 5, flexible beaconing allows more piconets, whereas the throughput shown in Figure 6 for flexible beaconing is higher than normal beaconing up to 20 extra users. Therefore we can indicate that for the case of 10.3 meter beacon range using flexible beaconing more advantageous than the normal beaconing for PNC1.

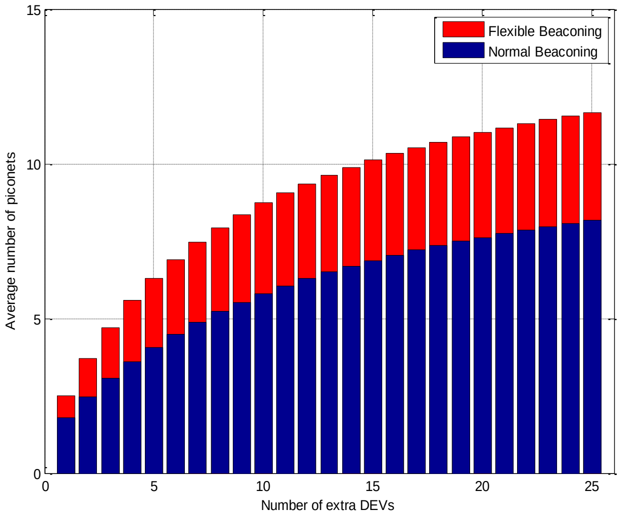

Figure 5 Average number of piconets (10.3m Beacon range)

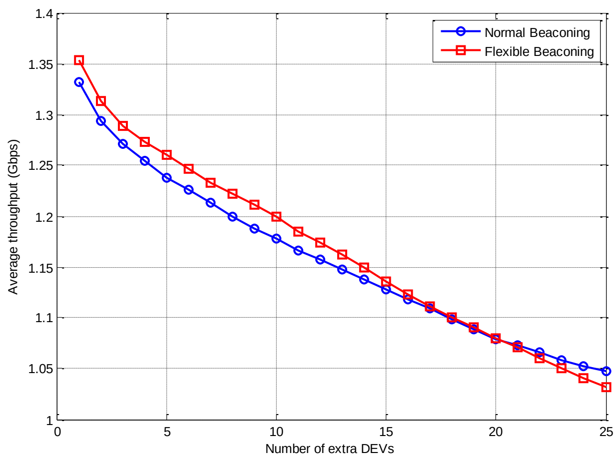

Figure 6 Average throughput between PNC1 and Victim-DEV with 10.3 m beacon range

Afterwards we simulated a longer range for beaconing, 13.6 m. In this case although flexible beaconing allows more piconets (Figure 7), the throughput is less the normal beaconing in all cases as shown in Figure 8.

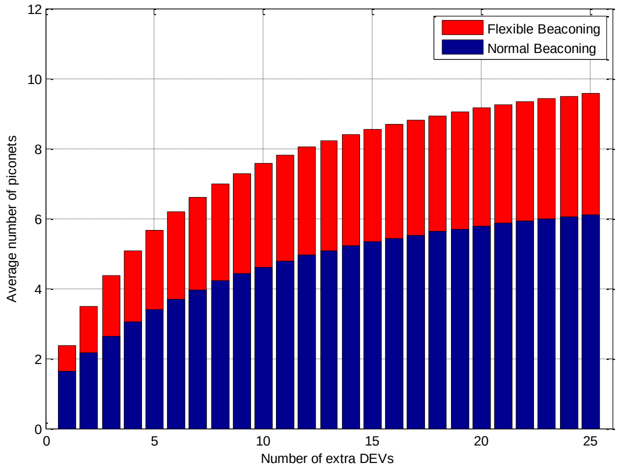

Figure 7 Average number of piconets (13.6m Beacon range)

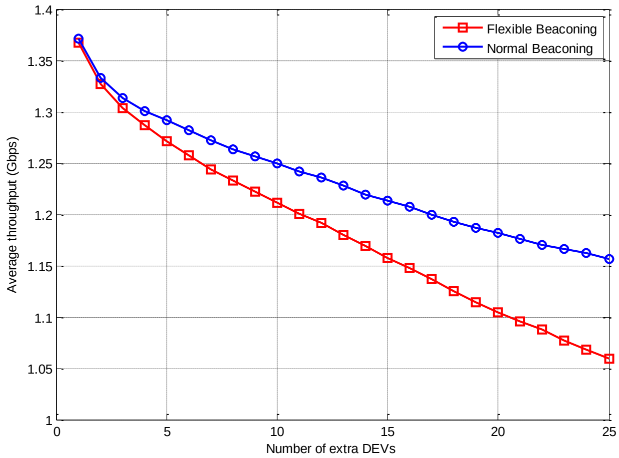

Figure 8 Average throughput between PNC1 and Victim-DEV with 13.6 m beacon range

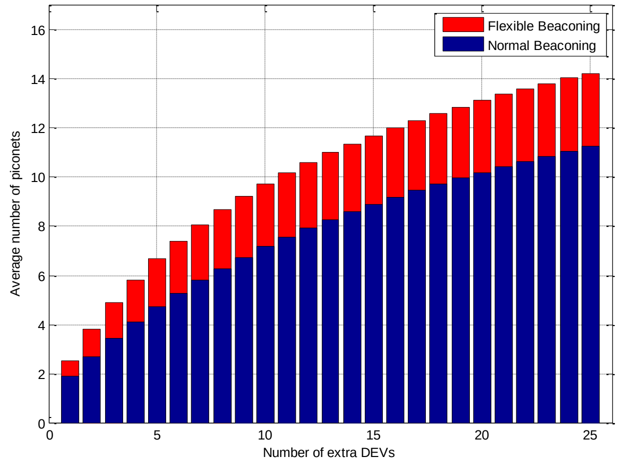

Figure 9 Average number of piconets (7.8 m Beacon range)

The reason is 13.6 meter is the longest beacon possible and in normal beaconing it provides the largest protective zone around the victim. As a result it ensures best throughput performance, while keeping number of possible piconet in minimum. Last set of simulations are for the case of a shorter 7.8 meters beacon range.

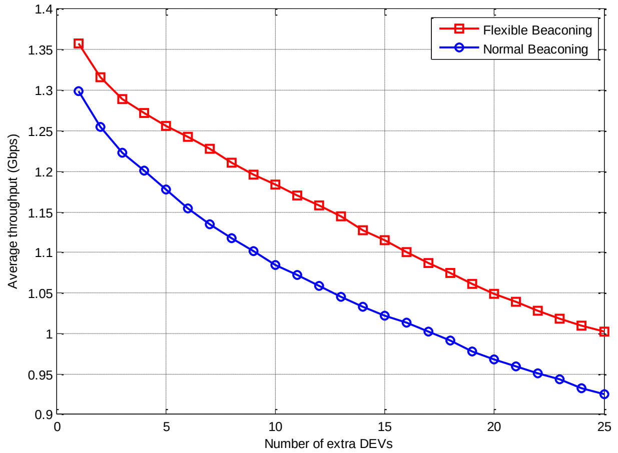

Figure 10 Average throughput between PNC1 and Victim-DEV with 7.8 m beacon range

In this case flexible beaconing is more beneficial for both the throughput and total number of receivers as can be seen in Figure 9 and Figure 10. The reason is the decrease in throughput due to using 5.9 m beacons is less than the increase of the throughput due to 10.3 m and 13.6 m beacons.

By comparing all simulation scenarios, we can conclude that the flexible beacon enables additional piconets in the area in all cases, whereas its protection of the Victim-DEV depends on the number of users and the beacon range of surrounding piconets. Nevertheless, if the number of users in the area is limited, the throughput of the Victim-DEV with flexible beaconing is comparable to the one with normal beaconing.

7. Conclusions

In this work we studied the effect of beacon range to 60 GHz system with piconet controllers. Our main focus was the cochannel interference between multiple piconets. We provided results of how different PHY modes behave under cochannel interference. We provided a simulation system based on these results to find the number of piconets in a given area and also throughput between the Victim Device and PNC. Instead of fixed range beacon scheme of 803.15.3c system, we suggested a novel flexible beaconing scheme. Our results indicate that flexible beaconing allows more piconets while keeping the throughput high. In 60 GHz bands, the attenuation and the dispersion of the cables may affect overall performance. In this work we assume all devices have the same length of cable but as a future work effect of cabling will be investigated.

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