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A Power-controlled Scheduling Scheme using a Directional Antenna in Smart Home

Yongsun Kim and Hoyong Kang

***Abstract*—**This paper proposes a power-controlled scheduling scheme for devices using a directional antenna in smart home. In the case of the home network using directional antenna, devices can concurrently transmit data in the same frequency band. Accordingly, the throughput increases compared to that of devices using omni-directional antenna in proportional to the number of concurrent transmissions. Also, the number of concurrent transmissions depends on the beamwidth of antenna, the number of devices operating in the network , transmission power, interference and so on. In particular, the less transmission power is used, the more concurrent transmissions occur due to small transmission range. In this paper, we considered sub-optimal scheduling scheme for throughput maximization and power consumption minimization. In the scheme, each device is equipped with a directional antenna. Various beamwidths, path loss components, and antenna radiation efficiencies are considered. Numerical results show that the proposed schemes outperform the scheduling scheme using directional antennas without power control.

***Keywords*—**Mmwave WPANs, directional scheduling, power-controlled scheduling scheme, smart home.

I. Introduction

THE smart home is anticipated to consist of many devices requiring high speed data such as wireless smart TV and A/V player as well as devices requiring low data rate. However, the existing 2.4 GHz WiFi or bluetooth is insufficient to meet their requirements since it uses omni-directional antenna, has small bandwidth and experiences interference among devices.

Accordingly, the utilization of a mmWave band, which is an ultra-wideband, is growing with the increase of use of wireless smart home applications requiring a high transmission rate, such as a wireless high-definition multimedia interface (HDMI) cable replacement for uncompressed video or audio streaming, a wireless universal serial bus (USB), an internet protocol television (IPTV)/video on demand (VoD), and a 3-dimensional (3D) game. Compared to the 2.4 GHz or 5 GHz frequency band, mmWave band has some unique characteristics that make possible many advantages, such as the strong immunity against interference, high security and efficient frequency reuse [1].

A scheduling scheme for concurrent transmissions using directional antennas is a crucial part of improving the performance measures of throughput and power consumption, and shows marked performance improvements compared with using an omni-directional antenna. Since mmWaves have a very short propagation range arising from oxygen absorption and high path loss, the use of directional antennas is highly recommended for communication over mmWave WPANs. A TDMA based scheduling scheme and an analysis on CSMA/CA for directional concurrent transmissions over mmWave WPANs were addressed in [2] and [3], respectively, in which all devices were assumed to use the same transmission power. A power-controlled scheduling scheme with an omni-directional antenna was considered in [4]. It introduced the concept of an exclusive region (ER) within which a transmitter can communicate with a receiver without any interference. In other words, each stream consisting of a transmitter and receiver pair has an ER around the receiver, and the transmitters of all other simultaneously sending streams should be located outside the ER of the stream for successful transmission. The average number of concurrent transmissions with power control was analyzed in [5]. This paper proposes a power-controlled scheduling scheme aiming at throughput maximization and power consumption minimization using a directional antenna based on IEEE 802.15.3c [6].

Y. Kim is with the Electronics and Telecommunications Research Institute, 138 Gajeongno, Yuseong-gu, Daejeon, 305-700, Korea (e-mail:doori@etri.re.kr).

H. Kang is with the Electronics and Telecommunications Research Institute, with the Electronics and Telecommunications Research Institute, 138 Gajeongno, Yuseong-gu, Daejeon, 305-700, Korea (e-mail:hoyong.kang@etri.re.kr).

II. System Model

A. Network Model

In the IEEE 802.15.3c network configuration, the devices associated with the piconet coordinator (PNC) perform neighbor discovery (ND) using a directional antenna in order to search for a peer device for future communication. In the ND process, each device delivers information, including the locations of its neighbors, to the PNC. Upon the completion of the ND process, the PNC announces the information on the dedicated channel time allocations (CTAs) by sending beacons, which indicate the reserved time slots for the requesting streams within a superframe, to the transmitter-receiver pairs. Since each device uses a directional antenna, PNC may allocate multiple CTA blocks with the same time duration to the streams that are concurrently transmittable.

Fig. 1 shows the superframe structure of IEEE 802.15.3c WPANs. During the CAP, DEVs should operate in a “listen before talk” manner, whereas during the CTAP, DEVs can communicate only in their allocated time period, which is referred to as channel time allocation (CTA) in a time division multiple access (TDMA) fashion. In IEEE 802.15.3c WPANs, the CTAP is mainly used for data communications between the DEVs to guarantee a reliable connectivity. In this paper, we consider only CTAP for concurrent transmissions.

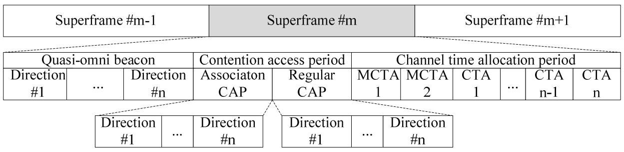

Fig. 1 IEEE 802.15.3c superframe structure

B. Antenna Model

This paper considers a cone plus circle antenna model as a directional antenna in order to reflect a more realistic environment [1]. The antenna gains of the model are composed of mainlobe and sidelobe gains, which are given by

$$G_m[dBi] = 10\log_{10}(2\pi\eta/\theta) \text{ and}$$

$$G_s[dBi] = 10\log_{10}\{2\pi(1-\eta)/(2\pi-\theta)\}, \quad (1)$$

respectively, where η and θ, $0<\theta\le 2\pi$, are the antenna radiation efficiency and mainlobe beamwidth. Fig. 2 shows radiation form for antenna model used in this paper.

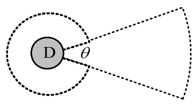

Fig 2 Radiation form for cone plus circle antenna model

C. Path Loss Model

Let $G_T(i)$, $G_R(i)$, and $r_{i,j}$ be the antenna gains of the transmitter and receiver of stream i, and the distance between the transmitter of stream i and receiver of stream j, respectively. The average received signal power of stream i is then given by

$$P_R(i)[dBm] = G_T(i)[dBi] + G_R(i)[dBi] + P_T(i)[dBm] - PL(r_{i,i})[dB] \quad (2)$$

where $P_T(i)$ and $PL(r_{i,i})$ are the transmission power and path loss of a stream. The path loss model for IEEE 802.15.3c is given by

$$PL(r_{i,i})[dB] = PL_0[dB] + 10\cdot\alpha\cdot\log_{10}\left(\frac{r_{i,i}}{r_0}\right)[dB] + X_\sigma[dB], \quad (3)$$

where r_0, PL_0 and X_σ are the reference distance given by $1m$, free space path loss at reference distance and the lognormal shadowing with mean zero. The path loss (PL) exponent α for mmWave-based measurements ranges from 1.2 to 2.0 for LOS and 1.97 to 10 for NLOS in various different indoor environments [7]. If we ignore the shadow fading and use the path loss exponent for a wide beamwidth when $\alpha = 1.53$ [5], $PL[dB]$ in a 60-GHz band is computed as follows:

$$PL[dB] = 10\log_{10}\{(4\pi/\lambda)^2 r^\alpha\} = 32.45 + 20\log_{10}(60) + 10\cdot\alpha\cdot\log_{10}(10) \quad (4)$$

where λ is the wavelength of the signal given by $\lambda = c/f$. c is the speed of light, and f is the frequency of the signal, which here is 60GHz. Note that the receiver sensitivity indicating the threshold of the received power for successful transmission, $P_R(i)$, is $-70dB$ in common mode signaling (CMS). If several streams can be transmitted simultaneously, the achievable data rate of stream i is given by

$$R_i = k_1 W \log_2\left\{\frac{\kappa G_T(i)G_R(i)P_T(i)r_{i,i}^{-\alpha}}{N_0 W + \sum_{i\ne j} I_{j,i}} + 1\right\} \quad (5)$$

where k_1, N_0, and W are the coefficient related to the efficiency of the transceiver design, the one-sided spectral density of white Gaussian noise, and the channel bandwidth, respectively. Also, κ is a constant proportional to $10\log_{10}(\lambda/4\pi)^2 = -68.0048dB$. $I_{j,i}$ is the interference power of stream i caused by stream j. which is given by

$$\begin{aligned} I_{j,i}[dB] = {} & \kappa[dB] + G_T(j)[dBi] + G_R(i)[dBi] \\ & + P_T(j)[dBm] - 10\cdot\alpha\cdot\log_{10} r_{j,i}. \end{aligned} \quad (6)$$

As shown in (6), the interference level varies according to the location, antenna gains, and transmission power of the interferer. In addition, it is noted that the data rates of streams for concurrent transmission may change due to different interference levels.

Let R_i^* be the average data rate of stream i during M slots when only one stream transmits at a time, which is given by $R_i^* = k_1 W \log_2\{\kappa G_T(i)G_R(i)P_T(i)r_{i,i}^{-\alpha}/N_0W + 1\}/M$. To ensure $R_i \ge R_i^*$, $\sum_{j\ne i} I_{j,i} \le (M-1)N_0W$, must hold as shown in [2]. Here, j is a stream scheduled to transmit concurrently with stream i. In other words, average interference level from any other streams should be less than that of background noise for concurrent transmissions. A sufficient condition can be replaced by a stronger condition, $I_{j,i} \le N_0W$, for all j, $j \ne i$, which allows for designing simpler and more practically feasible scheduling algorithms. Assume that the noise power spectrum is constant. No interferer should then be allowed inside an ER around the receiver to ensure that the interference power is less than the noise amount. Combining the sufficient condition and (6), the radius of the ER can be obtained as

$$r_{j,i} \ge \left\{\frac{\kappa G_T(j)G_R(i)P_T(j)}{N_0 W}\right\}^{1/\alpha}, \text{ for all } j. \quad (7)$$

Set $\{\kappa G_T(j)G_R(i)P_T(j)/N_0W\}^{1/\alpha}$ as the ER radius. Equation (7) illustrates that the radius of the ER of each transmitter-receiver pair may vary according to the antenna gains and transmission powers of the interferers, and any interferer should be at least ER radius away from the receiver for successful communication of a tagged transmitter-receiver pair.

III. Scheduling Schemes Description

This paper proposes a power-controlled scheduling scheme for mmWave WPANs in which two different objectives, throughput maximization and power consumption minimization, are considered. It is assumed

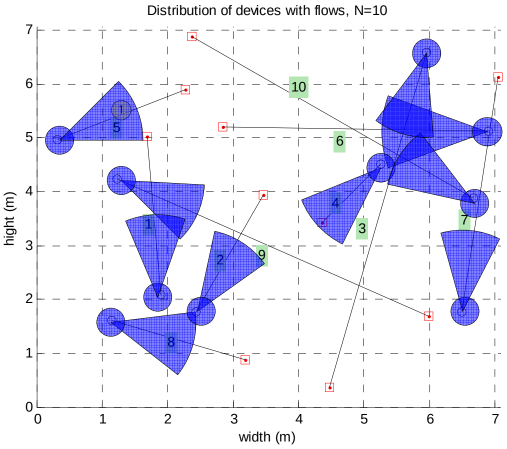

Fig. 3 An example of concurrent transmissions

that the stream loads $\{l_i\}_{i=1}^N$ are independent and identically distributed ($i.i.d.$) with an exponential distribution of parameter $1/d$, where d is an average traffic load for each device. It is also assumed that the data transmission rates of streams are all the same, while the transmission powers of streams vary depending on the distance between the transmitter and receiver of a stream. Fig. 3 shows an example of concurrent transmission. The streams contained in ovals can be concurrently transmitted.

The MaxT/MinP algorithm is as follows:

Step 1: Divide N traffic streams into several disjoint sets based on the ER criterion as follows. Each set consists of traffic loads corresponding to the stream that can be transmitted in the same CTA simultaneously. Denote the set as G_i and generate it as follows: Let $F=\{f_i : i=1,\cdots,N\}$ be the set of streams. The PNC randomly chooses a stream from F, inserts it into G_1, and then removes it from F. It then selects another stream in F and checks the ER conditions for concurrent transmission with each stream in G_1. If the newly selected stream is concurrently transmittable with each stream in G_1, it is put into G_1 and removed from F. Once the PNC completes checking the ER condition for the remaining streams in F, G_1 is generated. As for the remaining streams in F, the same procedure is used to generate G_2. Repeat these procedures until $F=\varnothing$. Assume that k, $k \le N$, groups are generated. Let l_{ij} and g_i be the load of stream j in group G_i and the number of traffic loads in the group, respectively, i.e., $G_i=\{l_{i1},\cdots,l_{ig_i}\}$. Then, $\sum_{i=1}^{k} g_i = N$ and $\sum_{j=1}^{g_i} l_{ij}$ loads can be transmitted into the same CTA block.

Step 2: For MaxT, each group, G_i, calculates the proportional load ratio, ρ^{G_i}, which is given by

$$\rho^{G_i} = \sum_{j=1}^{g_i} l_{ij} \Bigg/ \sum_{i=1}^{k}\sum_{j=1}^{g_i} l_{ij}. \tag{8}$$

For MinP, each group, G_i, calculates the ratio of the power consumption per load, σ^{G_i}, which is given by

$$\sigma^{G_i} = \sum_{j=1}^{g_i}\left(P_{ij}\cdot l_{ij}\right) \Bigg/ \sum_{j=1}^{g_i} l_{ij}, \tag{9}$$

where P_{ij} is the transmission power of the j th stream in G_i.

Step 3: Let $\{(\rho^G)_{(i)}\}_{i=1}^k$ $\left(\{(\sigma^G)_{(i)}\}_{i=1}^k\right)$ be the ordered set of $\{\rho^{G_i}\}_{i=1}^k$ $\left(\{\sigma^{G_i}\}_{i=1}^k\right)$, i.e., $(\rho^G)_{(1)} \ge \cdots \ge (\rho^G)_{(k)}$ $\left((\sigma^G)_{(1)} \le \cdots \le (\sigma^G)_{(k)}\right)$. Let $G_{(i)}$ be the group that corresponds to $(\rho^G)_{(i)}$ $\left((\sigma^G)_{(i)}\right)$ and $l_{(i)1},\cdots,l_{(i)g_{(i)}}$ be its elements. For notational simplicity, denote $(\rho^G)_{(i)}$ $\left((\sigma^G)_{(i)}\right)$ as $\rho^{G_{(i)}}$ $\left(\sigma^{G_{(i)}}\right)$. Transmit the loads belonging to $\{G_{(i)}\}_{i=1}^k$ in the order of $G_{(1)},\cdots,G_{(k)}$. If there are sufficient CTAs to allocate all of the groups within the current superframe, all the loads in all groups are sent.

Otherwise, only the groups in which all loads in the group can be transmitted in the remaining CTA blocks are transmitted according to the transmission order.

IV. Numerical Results

A. Performance Measures

The overall throughput and power consumption are obtained as follows: Provided m, $m \le k$, groups are transmitted, their overall throughput is given by

$$\sum_{i=1}^{m}\sum_{j=1}^{g_{(i)}} l_{(i)j} \Bigg/ \sum_{i=1}^{m}(T_{(i)} + mT_{guard}), \tag{10}$$

where $T_{(i)}$ and T_{guard} are the duration of the CTA block allocated to group $G_{(i)}$ and the guard time between adjacent CTA blocks, respectively. The overall power consumption is given by

$$\sum_{i=1}^{m}\sum_{j=1}^{g_{(i)}} l_{(i)j}P_{(i)j}, \tag{11}$$

where $P_{(i)j}$ is the transmission power of the j th stream in $G_{(i)}$.

B. Performance Evaluation

The parameters used are $W = 2{,}160MHz$ and $N_0 = -114dBm/MHz$. To obtain the transmission power of each stream, the received power, $P_R[dBm]$, is set to $-55dBm$, and P_T is fixed as $10mW$ in a non-power-controlled scheme, which are based on [3]. The active streams are distributed randomly in a LxL square room. It is considered that 5 to 50 active streams are deployed, and the room size varies according to the communication range, which is determined based on the beamwidth, data rate, and radio efficiency as shown in Table I. The average required time for transmission is assumed to be $20m\sec$, which is denoted simply as $d = 20m\sec$. Also, $\theta = 30^\circ \sim 180^\circ$ and $\eta = 0.9$ are used for numerical results.

TABLE I
THE ACTUAL TRANSMISSION RANGE UNDER IEEE 802.15.3C (UNIT: *M*)

Beamwidth(θ)	Tx range(η=1) *R*: 0.412/1.65*Gbps*	*L*	Tx range(η=0.9) *R*: 0.412/1.65Gbps	*L*
30°(α = 1.73)	26.35/11.86	18.63/8.38	23.33/10.50	16.46/7.42
60°(α = 1.73)	11.82/5.32	8.36/3.76	10.47/4.71	7.40/3.33
90°(α = 1.73)	7.40/3.33	5.23/2.35	6.55/2.95	4.63/2.08
120°(α = 1.73)	5.31/2.39	3.75/1.69	4.50/2.11	3.32/1.49
180°(α = 1.73)	3.88/1.57	3.38/1.37	2.39/0.97	1.59/0.64

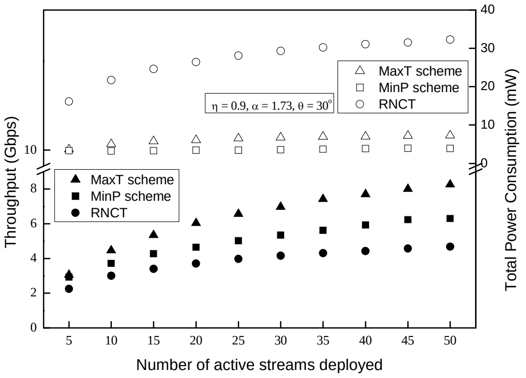

Fig. 4 Throughput and power consumption

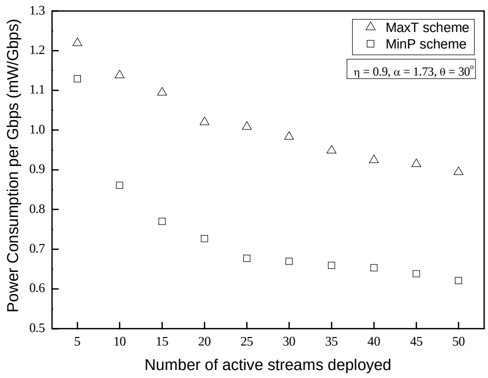

Fig. 5 Power consumption per Gbps

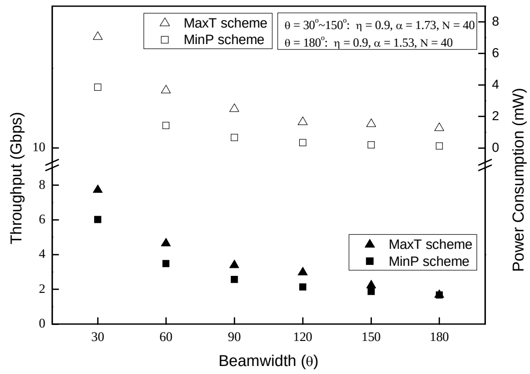

Fig. 6 Throughput and power consumption per Gbps

The performances of the proposed schemes are compared with a randomly-selected non-power-controlled concurrent transmission (RNCT) scheduling scheme. Fig. 4 compares the throughput and power consumption, and shows that the throughput and power consumption increase as the number of streams increase in the MaxT/MinP scheme. The figure also shows that MixT is better in terms of throughput, while MinP is better in terms of power consumption, which complies with the purpose of the schemes. Both schemes have good performances compared with RNCT in both metrics. Fig. 5 shows the power consumption per Gbps. It indicates that MinP has lower power consumption per Gbps than that of MaxT. Since the loads of the groups consuming the lower power are sent prior to the groups consuming the higher power, the groups consuming the higher power remain untransmitted with high probability. This provides lower power consumption per Gbps as the number of streams increases. Fig. 6 shows the throughput and power consumption for varying beamwidths when 40 streams are deployed. The figure demonstrates that in the MaxT/MinP scheme the throughput decreases while the power consumption increases with an increase in antenna beamwidth. This arises from the fact that a wider beamwidth leads to greater power consumption to maintain the transmission range.

V. CONCLUSION

The proposed scheduling scheme for a directional concurrent transmission provides better performance in terms of throughput and power consumption compared to a randomly selected scheduling scheme without power control.

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REFERENCES

[1] S. K. Yong, and C. C Chong, “An overview of multigigabit wireless through millimeter wave technology: potentials and technical challenges,” EURASIP Journal on Wireless Communications and Networking, vol. 2007, no. 1, January 2007.

[2] L. X. Cai, L. Cai, X. Shen, et al., "REX: a Randomized EXclusive Region based Scheduling Scheme for mmWave WPANs with Directional Antenna," IEEE Trans. on Wireless Communications, vol. 9, no. 1, 2010.

[3] M. Kim, Y. Kim, and W. Lee, "Performance Analysis of Directional CSMA/CA for IEEE 802.15.3c under Saturation Environments," ETRI Journal, vol.34, no.1, February 2012.

[4] B.J. Radunovic and Le Boudec, "Optimal Power Control, Scheduling, and Routing in UWB Networks," Selected Areas in Communications, IEEE Journal on, vol 22, pp 1252-1270, September 2004.

[5] Y. Kim, M. Kim, W. Lee, et al., "Power Controlled Concurrent Transmissions in mmWave WPANs," IEICE Transactions on Communications, appear to vol. E93-B, no. 10, Oct. 2010.

[6] IEEE P802.15.3c, IEEE 802 Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs): Amendment 2: Millimeter-wave based Alternative Physical Layer Extension, October 2009.

[7] P. Pagani, I. Siaud, N. Malhouroux, et al., "Adaptation of the France Telecom 60 GHz Channel Model to the TG3c Framework," IEEE P802.15-06-0218-00-003c, April2006.