Combining Concurrent Transmissions Scheduling and Power Allocation for Multimedia Content Distribution in 60 GHz based Indoor Networks

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Abstract

60 GHz millimeter wave (mmWave) technology offers the potential for multi-Gbps indoor applications. In this paper, we apply this technology for multimedia content delivery in indoor network where devices are battery-constrained. We first schedule the concurrent transmissions by using vertex coloring algorithm. Then, we consider the power allocation problem to optimize the aggregate network utility in each timeslot. Numerical results show that our proposed scheme can decrease the number of timeslots as well as improve the aggregate network utility.

1. Introduction

60 GHz is a promising technology to support applications that require gigabit data rate. However, the signal in this network decreases more dramatically than traditional sub 6 GHz band. To deal with this problem, directional antenna or beamforming is used to compensate propagation loss. Since in directional communication, transmission energy focuses toward a specific direction, idle spaces can be created. Neighbor devices can utilize these idle spaces to transmit and receive data. In other word, the utilization of directional communication permits multiple concurrent transmissions which improves network throughput. Besides, standard such as IEEE 802.15.3 [1] is designed to achieve very high throughput in mmWave WPAN networks. However, in this existing standard, each timeslot is allocated to one pair of transmitter and receiver, which does not fully exploit the potential of concurrent transmissions. In addition, how to schedule multiple transmissions in the same timeslot to improve throughput is important and challenging issue.

Typically, multimedia content delivery consumes more energy than other low rate services because it is delay sensitive and requires high data rate. But, many portable devices in smart home have a limited lifetime because they depend on battery. Therefore, it is essential to manage resource such as power efficiently.

In this paper, we consider a scenario where multiple pairs of users deliver multimedia content in a small room or house. Firstly, we try to schedule concurrent transmissions by using vertex coloring scheduling algorithm [2]. Then, in each timeslot, power allocation problem is considered to maximize the utility function and satisfy QoS requirements of all links scheduled to transmit in this timeslot.

The rest of this paper is organized as followed. In Section II, we describe the transmission data rate. In Section III, the vertex coloring scheduling algorithm is presented. Utility functions and power allocation problem formulation are considered in Section IV. Some numerical results are presented in Section V and conclusions are drawn in Sections VI.

2. Transmission Data rate

We assume that the average link throughput is affected by the path loss. d_i is the distance between source device T_i and destination device R_i of link i. The path loss at distance d_i in dB can be modeled as:

$$h_{i,i} = \begin{cases} PL(d_i), d_i \le d_0 \\ PL(d_0) + n10\log_{10}(\frac{d_i}{d_0}), d_i > d_0 \end{cases} \quad (1)$$

Where n is the path loss exponent and is usually in the range of 2 to 6 for indoor environment. $PL(d_0)$ is the path loss function at the reference distance d_0 and can be calculated by Friis equation for free space transmission.

With p_i is the transmission power of transmitting device of link i, the achievable data rate for this link:

$$r_i \le \eta B \log_2[1 + \frac{p_i h_{i,i}}{N_0 B + \sum_{i \ne j} p_j h_{j,i}}] \quad (2)$$

Where B is bandwidth, $\eta \in [0,1]$ is the coefficient describing the efficiency of the transceiver design, N_0 is the one-side noise power spectral density.

3. Scheduling based on Vertex Coloring Algorithm

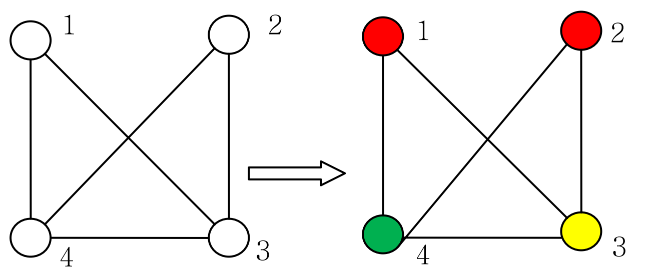
a. Condition for Concurrent Transmissions

Concurrent transmissions may suffer from the possible interference from other transmitters. In [3], the authors introduced an exclusive region [ER] around the receiver, which is defined as the threshold distance that the mutual interference can be seen as background noise. After comparing the distance between transmitter and receiver of the link with the radius of ER, we can derive the possibility of concurrent transmission for different links.

b. Scheduling Algorithm

In [2], the authors proposed the vertex coloring based scheduling algorithm. Based on the concurrent transmission introduced earlier, conflict matrix is constructed. The dimension of the conflict matrix is V_N x V_N, where V_N is the total number of links. Element 1 in matrix shows that there is a conflict between the corresponding links while element 0 indicates concurrent transmissions are allowed between the corresponding links. The conflict matrix can be represented by a conflict graph. In the conflict graph, vertices show the links and the edges between vertices express the links' mutual conflict. After that, they apply the vertex coloring to color the vertices in the conflict graph with the minimum number of colors. The principle of vertex coloring is that neighboring vertices linked with each other in the conflict graph will be colored differently. By this way, multiple links can be transmitted simultaneously in one timeslot. Network throughput is improved and the number of timeslots is minimized. Following is an example.

$$Conflict\ Matrix_{(4\times4)} = \begin{bmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$



We can transmit link 1, 2 in the first timeslot, link 3 in the second timeslot and link 4 in the third timeslot.

4. Utility Functions and Problem Formulation

In order to characterize the users' satisfaction, the utility function of the transmitting and receiving pair of link i is proposed in [4]:

$$U_i(\mathbf{p}) = w_i^r U_i^r(r_i(\mathbf{p})) + w_i^p U_i^p(r_i(\mathbf{p})) \quad (3)$$

Where $U_{i=}^{r}(r_i(\mathbf{p}))$ represents users' satisfaction about the effective throughput $r_i(\mathbf{p})$ and $U_{i=}^{p}(r_i(\mathbf{p}))$ shows the energy consumption, $w_{i=}^{r}$ and $w_{i=}^{p}$ are weighting factors that balance the utility about throughput and energy consumption. With L is set of links in one timeslot, $\mathbf{p} = \{p_1, p_2, ..p_L\}$.

$U_{i=}^{r}(r_i(\mathbf{p}))$ is defined in [4] :

$$U_i^r(r_i(\mathbf{p})) = K_{1i} \ln(1 + K_{2i} \log_2(1 + r_i - r_i^{\min})) \quad (4)$$

Where coefficients K_{1i} and K_{2i} depend on the applications. This function is widely used for delay sensitive application. $U_{i=}^{p}(ri(\mathbf{p}))$ is used in [4]:

$$U_i^p(r_i(\mathbf{p})) = -\frac{p_i}{L_i} \quad (5)$$

Where L_i is a number that characterizes the battery's capacity of transmitter of link i.

The utility maximization problem can be formulated as:

$$\text{Maximize } (\mathbf{p}) \quad U = \sum_{i \in L} U_i(\mathbf{p}) \quad (6a)$$

$$\text{Subject to} \quad 0 \le p_i \le p_i^{\max}, \forall i \in L \quad (6b)$$

$$r_i \ge r_i^{\min}, \forall i \in L \quad (6c)$$

Where constraint (6b) indicates that the power consumed by link i is no greater than p_i^{max}, constraint (6c) guarantees the QoS requirement of link i.

5. Numerical Results

In this section, we consider the average distance between devices is 1.5 m. The bandwidth is 1800 MHz, the noise power spectrum density is -134 dBm/Hz. $K_{1i} = 1$, $K_{2i} = 0.7$, $r_i^{min} = 0.95$ Gbps, for link i using uncompressing video streaming applications. $K_{1i} = 1.5$, $K_{2i} = 1$, $r_i^{min} = 1.54$ Gbps for link i using work station and conference ad-hoc applications. $w_{i=}^{r}$ and $w_{i=}^{p}$ are 1 and 10 respectively, $L_i = 1000$, $\forall i$.

Firstly, we compare our proposed scheme with the traditional TDMA with respect to the average number of links per timeslot. From the table 1, the average links per slot in the former scheme is higher than the one in the latter.

Table 1. Average links per slot.

Scheme\Links	4	6	8	10
Proposed Scheme	1.39	1.52	1.62	1.72
TDMA	1	1	1	1

We also compare the aggregate utility per link in our scheme and in IEEE 802.15.3c standard when the number of links are 4, 6, 8, 10. The table 2 shows that our scheme outperforms.

Table 2. Average utility per link.

Scheme\ Links	4	6	8	10
Proposed Scheme	4.22	4.12	4.17	4.19
802.15.3c	2.63	2.65	2.64	2.59

6. Conclusions

In this paper, we proposed scheme combining scheduling and power allocation for multimedia content delivery in 60 GHz indoor network. We apply the vertex coloring algorithm to scheduling the concurrent transmissions and then formulate the power allocation problem to optimize the aggregate utility in each time slot. The numerical results showed that our scheme outperforms compared with the existing TDMA based IEEE 802.15.3c.

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8. References

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