Study Channel Hopping Sequences in BT Mesh Networks to Improve Packet Forwarding Efficiency

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***Abstract* — BT (Bluetooth) mesh network adopts channel hopping and advertising method to transmit data packets. In early specification, three advertising channels and fixed hopping sequence (Ch37, Ch38, Ch39) are designed for BT mesh networks. However, when there are a large number of relay nodes deployed in the network and a large number of data packets needed to be transmitted, the advertising method and fixed hopping sequence may cause serious packet collision and reduce packet forwarding efficiency. Hence, this paper will focus on the influence study of channel hopping sequences on packet collision in an advertising environment. Based on the random distribution mesh network, this paper simulates and compares the performances of fixed hopping sequence and three proposed random hopping sequences. The results show that the proposed random hopping sequences can effectively reduce the probability of packet collision and further improve packet forwarding efficiency in the BT mesh networks.**

I. Introduction

The BT (Bluetooth) mesh network technology is one of the important transmission technologies for IoT (Internet of Things). In particular, the application of ESL (electronic shelf label) system in smart buildings is an important application area in the SIG (Bluetooth Special Interest Group) plan. The SIG predicts that 334 million BT ESL devices will ship by 2027. The leaders from the ESL industry teamed with the SIG to create a scalable, ultra-low power, and highly secure ESL wireless standard based on BT technology [1].

ESL system has the characteristics of deploying a large number of BT nodes (relay nodes) and transmitting a large amount of data packets. However, the BT mesh network sends data packets to a destination node in an advertising (broadcasting) or flooding manner. Therefore, applications like the ESL system will easily generate broadcast storms in a BT mesh network, cause serious packet collision and reduce packet forwarding efficiency. In the past few years, many researchers have been investigating various packet collision problems in both BT and BT mesh networks [2-4].

Therefore, this paper will focuses on the influence study of channel hopping sequences on packet collision in an advertising environment. The earlier BT specification defined the fixed hopping sequence for three advertising channels (Ch37, Ch38, Ch39). In BT specification v5.1, the definition was modified to support the random hopping sequence. The simulation results in this paper show that the proposed random hopping sequences can effectively reduce the probability of packet collision and further improve the packet forwarding efficiency in the BT mesh networks.

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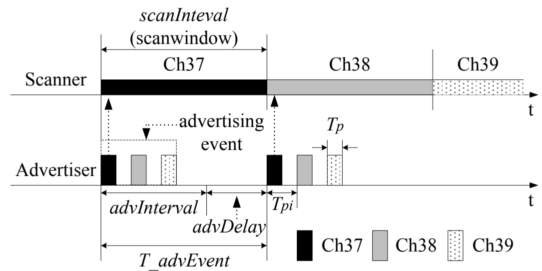

Fig.1. Behavior and parameters of advertiser and scanner.

II. Channel Hopping Sequences

A. Behavior and Parameters in BT Mesh Transmission

In BT mesh networks, a node transmitting (advertising) packets is an advertiser, which can be a source node or a relay node. A node receiving packets is a scanner, which can be a relay node or a destination node. Each packet sent by an advertiser is called an advertising event. The time interval between adjacent advertising events is "T_advEvent", which contains a fixed "advInterval (T_{ai})" and a random delay "advDelay (T_{ad})". Each "advInterval" contains the transmission time of 3 advertising channels (i.e., Ch37, Ch38, Ch39), as shown in Fig. 1. When an advertiser transmits a packet, then the 3 channels will advertise the same packet. The BT specification v5.2 defines the range value of the "advInterval" as 20ms~10,485.759375s. The value of "advDelay" is 0~10ms. On the other hand, a scanner will scan all advertising channels periodically. Each scan of a channel will cover at least one advertising event of the advertiser. The time interval for scanning a channel is "scanInterval (scanwindow)", and its value must be less than 40.96 seconds.

B. Fixed Hopping Sequence and Random Hopping Sequence

Based on BT specification v5.1, it supports both channel hopping sequences: fixed hopping sequence (Ch37, Ch38, Ch39) and random hopping sequence. In this paper, three random hopping sequences (called Rand-*x*) are proposed and compared with the fixed hopping sequence. The different permutations of hopping sequences are shown in Table I.

Three random hopping sequences proposed in this paper are called as Rand-6, Rand-24, and Rand-27 (Rand-*x*, *x* is 6, 24, or 27). Referring to Table I, the Rand-6 adopts the hopping sequences of index 1~6. The Rand-24 adopts the hopping sequences of index 1~24. Rand-27 adopts the hopping

TABLE I. INDEX OF RANDOM CHANNEL HOPPING SEQUENCES

Index	Hopping Sequences	Index	Hopping Sequences
1	Ch37 Ch38 Ch39	15	Ch38 Ch38 Ch37
2	Ch39 Ch37 Ch38	16	Ch38 Ch38 Ch39
3	Ch38 Ch39 Ch37	17	Ch38 Ch37 Ch38
4	Ch37 Ch39 Ch38	18	Ch38 Ch39 Ch38
5	Ch38 Ch37 Ch39	19	Ch39 Ch38 Ch38
6	Ch39 Ch38 Ch37	20	Ch39 Ch37 Ch37
7	Ch37 Ch38 Ch38	21	Ch39 Ch37 Ch39
8	Ch37 Ch39 Ch39	22	Ch39 Ch38 Ch39
9	Ch37 Ch37 Ch38	23	Ch39 Ch39 Ch37
10	Ch37 Ch37 Ch39	24	Ch39 Ch39 Ch38
11	Ch37 Ch38 Ch37	25	Ch37 Ch37 Ch37
12	Ch37 Ch39 Ch37	26	Ch38 Ch38 Ch38
13	Ch38 Ch37 Ch37	27	Ch39 Ch39 Ch39
14	Ch38 Ch39 Ch39		

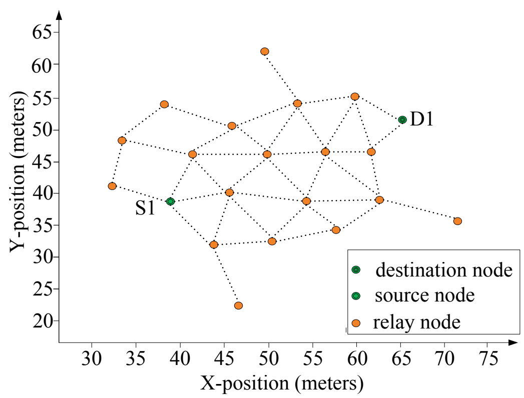

Fig.2. The simulation architecture of a random distribution mesh network.

sequences of index 1~27. Using the random hopping sequences for packet transmission, an advertiser only needs to execute a random number generator and use its unique device address (48-bit) to be a random seed. The required cost (overhead) is the same as the fixed hopping sequence.

III. SIMULATION TESTS AND CONCLUSION

Based on the description in section II, if the "advInterval" of an advertiser is 20ms, the average delay of "advDelay" is 5ms, then the value of "T_advEvent" is 25ms. Thus, the advertiser can transmit up to 40 different PDUs (packets) per second in Link layer, and Physical layer can transmit up to 120 advertising packets per second (in 3 advertising channels). The maximum size of a packet is 47-byte (376-bit). The maximum throughput of an advertiser is 45120bps (45.12Kbps) [5]. Therefore, in this section, the simulation traffic loads are set to 30, 60, 90, and 120 packets per second. The transmission speed in Physical layer is 1Mbps.

The simulation tool is MATLAB and the version is 2022a. The fixed hopping sequence and three proposed random hopping sequences (Rand-6, Rand-24, and Rand-27) are simulated. The simulated BT mesh network adopts the random distribution network with 21 BT nodes. It is in a rectangular area of 75m× 65m, the distance between nodes is 4.8~9.6 m, and the radio wave coverage range of each node is 10m, as shown in Fig. 2. The average collision rate (%) of packets and the successful received rate (%) of packets are calculated to compare the performance of these four hopping patterns.

In the random distribution mesh network, the average collision rate (%) and the successful received rate (%) are showed in Fig. 3 and Fig. 4. For the Rand-27, although it has the lowest average collision rate, but its successful received rate is also the lowest because the receiver (scanner) is not easy to receive (scan) packets in some hopping sequences, such as Ch37, Ch37, Ch37, etc. However, for the Rand-6, although its average collision rate (%) is not the lowest, but its successful received rate (%) is the highest. Therefore, Rand-6 has the best packet forwarding efficiency.

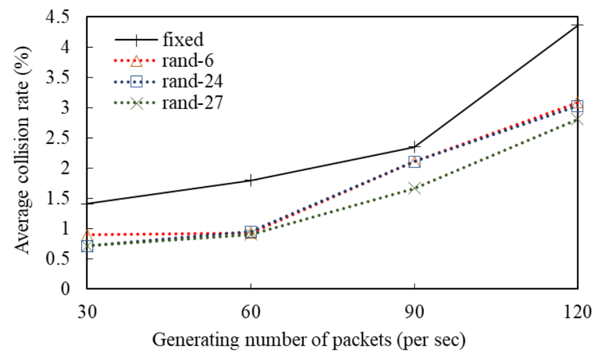

Fig.3. The average collision rate (%) in a random distribution mesh network.

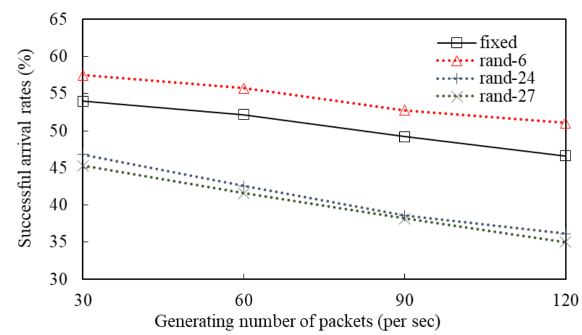

Fig.4. The successful received rate (%) in a random distribution mesh network.

ACKNOWLEDGMENT

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