Project-Based Network Simulation of Campus Remote Seat Booking System

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***Abstract*— This paper gives insights on extending a proposed remote seat booking prototype across campus and how to deploy the network sensors and controllers over a wide range based on computer simulations. A typical floor of an actual building at the University of Nottingham Ningbo China was picked to perform the network simulation. That includes a variety of common study rooms, computer rooms, and administrative rooms. The floor is divided into regions and rooms based on a few factors such as the room's nature, size, and function of each region. The simulation of the proposed network is presented and analyzed using different scenarios for different rooms. In each simulation scenario, end-to-end delay, and global MAC throughput were considered to evaluate the network performance. A compromise between those two factors was made to maintain the proposed system, cost-effective, flexible, and maintain power consumption reduction. The findings show that the network design, topology, and the total number of sensor nodes will generally depend on the region or the room size where the network is implemented.**

Keywords*— Project-Based, Smart Campus, Educational Technologies, Digital Transformation, Wireless Sensor Network Simulation.

I. Introduction

In the engineering education process, project-based learning is critical. On the one hand, it assists engineering students in developing numerous abilities necessary for their future employment, such as critical thinking, teamwork, cognition, and leadership [1, 2]. On the other hand, project-based learning assists undergraduate engineering students in better understanding and practicing the research process [3]. Furthermore, it is thought that student participation in projects that tackle real-world problems could aid in the development of a diverse variety of future graduates with the academic and professional skills needed for success in their postgraduate studies and future careers [4]. Project-based learning can also play a key role in digital transformation in higher education when academic and research staff collaborate with their students on employing their knowledge and skills to identify and analyze the existing challenges and workout innovative solutions [5].

This paper presents the network modeling and simulation of a campus seat management system as an outcome of project-based research. This network is used to implement an Internet-of-Things (IoT) application using Zigbee nodes that solves multi-seat booking in study areas during the congested periods of the final exams. The paper aims to propose a cost-effective and flexible wireless network structure within certain study areas that could be extended across the whole campus in the future.

IoT has been used in various smart campus applications that assist the teaching and learning process. That includes IoT flipped classrooms and student feedback [6]. Some campus applications use IoT in other learning environments, such as IoT smart laboratories that use mobile technologies to monitor and control lab activities [7]. Other campus solutions have been proposed to assist the classroom environment by developing smart chairs that aid attendance monitoring. While some other applications commonly use IoT for campus environmental monitoring purposes [8] or smart campus monitoring and access control [9]. IoT has also been used in seat management applications over the past decade. Some applications use smart seats to detect seat occupancy in public transportation [10, 11]. Some smart IoT-based solutions have been developed using Near-Field Communications (NFC) sensors in applications like restaurant management systems. This facilitates customers with a convenient dining experience, including accessible parking of their cars, finding an available table within the restaurant, ordering and paying [12].

The rest of this paper is structured as follows: Section 2 presents the architecture of the proposed intelligent seat booking system. While the modeling and design of the wireless sensor network is introduced in section 3, section 4 discusses a few simulation scenarios in various study rooms. Section 5 describes the results and recommendations, and section 6 concludes.

II. Proposed Seat Booking System Design

The proposed system is an application for using the IoT in an intelligent campus. Fig. 1 depicts the overall architecture of the system. A wireless sensor network is used to detect the availability of vacant seats in common study rooms. Different wireless network nodes are organized into small groups or subgroups at a smaller scale. Each group is responsible for a small area, such as a study room on a campus building floor. A sensor node is installed in each network site seat. All study room's sensor nodes are linked to a coordinator, another sensor node responsible for connecting the sensors group to the rest of the network. All network coordinators are linked to a gateway that connects the entire wireless sensor network to the Internet. Zigbee technology was utilized to implement the intended wireless sensor node in this project because of its many benefits. This comprises low-data-rate, low-cost, and low-power bidirectional wireless communication. As a result, less node and battery maintenance are required, lowering costs significantly. Zigbee can also use an ad-hoc network, which provides network flexibility for future network expansion to include more study rooms. It can also assist in reestablishing communication with the coordinator if one of the network nodes becomes disconnected.

Students can look for and book vacant seats in common study spaces using their smartphones. This can be accomplished through a front-end user interface, such as an App that runs on an internet-connected smartphone or tablet [13]. Seat multi-booking, which occurs when a student reserves a seat and then leaves the site, can be considerably reduced by the system, especially during high exam season.

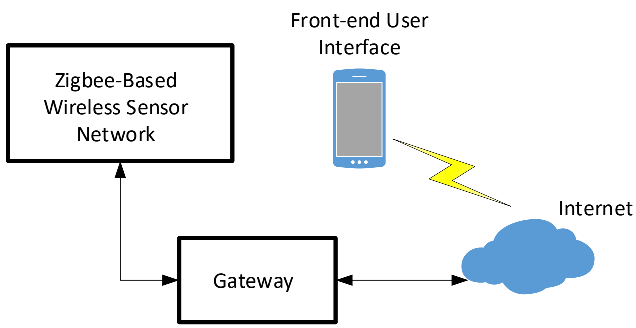

Fig. 1. Proposed system architecture.

III. Wireless Sensor Network Design and Modeling

Network simulation and modeling are crucial for any wireless sensor network before deploying or implementing the wireless nodes. Simulation can give insights into how the network architecture can be optimized and how the performance can be evaluated and validated. Among other available network simulator tools such as NS-2, J-Sim, EmStar, OPNET simulator has been selected to perform the modeling of the Zigbee-based WSN in the proposed design [14]. This is because OPNET is better suited to simulating real-world network behavior. Developing existing systems can demonstrate the flexibility in investigating network modeling of simulation in applications, equipment, protocols, and network communications [15]. It also provides an industry-leading environment for network technology development [16].

An actual building on the campus site was chosen to model the Zigbee wireless network. The majority of the rooms in that building are used for teaching and as common study rooms. The first floor of the building was picked in the simulation because it consists of a variety of study rooms, including computer rooms. It also contains other regions for student services and facilities.

A. *Network Topology*

Although IEEE 802.15.4 can realize star, tree, a cluster tree, and mesh topologies, ZigBee supports only star, tree, and mesh topologies [17]. In the star topology network, there are no routers. All the end devices communicate directly with the coordinator. The whole network operation is highly dependent on the coordinator which will become the bottleneck of the network. In the tree topology network, one coordinator acts as the central root node, several routers, and end devices. The router can be used as a relay and extend the coverage of a network. Both the router and coordinator can be a parent and have child nodes. The end devices can only be child nodes, and all of them communicate only with their parent nodes. Any packet exchange between two child nodes has to go through their common parent even if they are geographically close. Thus, if a parent node is disabled or runs out of energy, these child nodes connecting to this disabled parent cannot communicate with other devices in the network. The self-healing mechanism of this topology is relatively poor. The mesh topology is also called peer-to-peer topology. In this kind of network, there is one coordinator, several routers, and end devices. This topology can realize a multihop function. Routers are interconnected and can communicate with each other, resulting in better self-healing performance. Once a path fails, the end devices can send the packet to the destination through alternative paths. But it has a more complex routing protocol.

B. *Zigbee WSN Parameters*

CC2530 modules were used to build the WSN nodes in the proposed design. The required parameters for modeling and simulations are shown in Table 1.

TABLE I. Zigbee Parameters

Physical layer			
Data rate	250 Kbps		
Packet reception power threshold (dBm)	388.4335		
Transmission band	Worldwide (2450 MHz)		
Transmission power (W)	0.01204		
Network parameter			
Topology	Tree	Mesh	Star
Maximum children	22	22	255
Maximum routers	5	5	0
Maximum depth	5	5	1
Router discovery	×	10	×
Application traffic			
Destination	Parent		
Packet interval time (secs)	Constant (1.0)		
Packet size (bits)	Constant (256)		
Start time (secs)	Uniform (20,21)		
Stop time (secs)	Infinity		

The current and voltage levels from [18-19] are used to calculate the transmitted power parameter in the transmission mode. The number of nodes and routers used in the simulation were adjusted based on the requirements in the actual site. Other parameters such as the beacon order and superframe order are defined in IEEE 803.15.4. They specify the number of data packets transmitted in a network and the length of the inactive period of the network [20].

IV. Simulation Scenarios

Three different spaces were selected on the first floor of the teaching and student services building for the simulation. The room variety introduces three different simulation scenarios investigating the Zigbee network performance regarding the end-to-end delay and global MAC throughput for each scenario. The star, tree, and mesh topologies were evaluated for each scenario, to optimize the network structure across the campus.

A. Computer Room

The room is usually used for computer lab-based teaching. Alternatively, when the room isn't scheduled for teaching, it is used as a common study room. The room has 70 seats, and it's of an area of 17m × 13m. In this scenario, 70 end devices were assumed to represent the sensor nodes attached to the seats. The network parameters shown in Table 1 were used for the simulation using star topology, allowing 255 child devices with no routers. Four routers were added to the simulation scenario in the tree and mesh topologies, while the maximum number of the child nodes was adjusted to 20 for each parent node. There were 5 parent nodes in this scenario, and 4 of them were acting as child nodes of other parents. The network capacity, in this case, can have up to 96 end devices. The network structure for the star and tree topologies for the simulation of the Zigbee network in the computer room is shown in Figs. 2, and 3 respectively. The structure in the case of the mesh topology is similar to that in Fig. 3, with the ability for the routers to interconnect with each other.

B. Student Service Center

This is a larger space used for academic services. There are 11 desks for receptionists and three chairs in the waiting area. It's of a size slightly more significant than the self-study room but much smaller compared to the wide area of the whole floor. However, this center has fewer obstacles compared with the common self-study room. In this scenario, the three topologies were again used to compare the network performance. There are only 14 sensor nodes in total as the number of seats isn't as large as in the computer room. A sensor node was assumed to be attached to each available seat.

C. Open Study Areas Across the Whole Building Floor

There are wide areas for common study in the same building floor. The available seats in those areas can be used to extend the remote seat booking system by installing a wireless node on each seat. To compare the network performance with that in small size rooms, another simulation scenario was done to optimize the network structure when implemented across the whole floor. Due to the long distance between the source and the destination, in this case, the single-hop star topology cannot be implemented in a large area with several rooms, and both the single-hop power consumption and end-to-end delay are beyond the acceptable range. In addition to that, there's a large number of nodes compared to that within a specific room such as the computer room, which will increase the packet collision. In this case, due to its centralized nature, the star topology is more likely to be a bottleneck, and as a result, the packet drop rate increases. The routers between end devices and coordinators can enable the network to be more decentralized, leading to a state of load balance [21]. Thus, tree or mesh topologies should be utilized to meet the demand of a large-scale network.

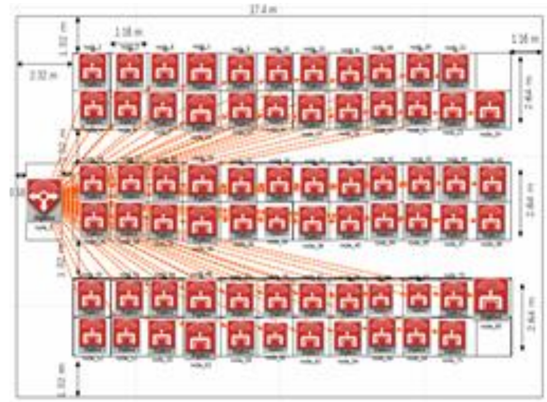

Fig. 2. Network structure in computer room using star topology

Fig. 3. Network structure in computer room using tree topology

V. Simulation Results and Recommendations

This section compares the network performance of various topologies in different site locations. Two factors have been used to evaluate the network performance: the total delay spent from the packet creation to reception and the total number of bits/secs forwarded among all WPAN network nodes from the MAC layer to higher layers.

Fig. 4 shows the end-to-end delay comparison among the star, tree, and mesh topologies in a computer room. In contrast, Fig. 5 shows the throughput comparison among those topologies within the same space. The results demonstrated in Fig. 4 indicate that star topology's network structure achieves a minimum delay in a small area like a computer room. The distance between the source and destination nodes is short and less than 20 meters. End devices can be directly connected to the corresponding coordinator by a single hop without a router. This will also minimize the power consumption, which leads to less battery maintenance. However, as indicated in Fig. 5, the star network topology has the lowest throughput compared with the throughput achieved using tree and mesh topologies. The end-to-end delay of the mesh topology slightly outperforms that of the tree topology. This can be attributed to the better congestion control achieved using multipath routers in the case of the mesh topology. Due to the nature of this project, the required packet size is very small, 256 bits. The throughput difference will not be considered a limitation in the case of a small-scale Zigbee network in a small size room. In this case, a compromise can be made to maintain low complexity and power consumption at fair throughput. Therefore, star topology can be considered the best choice when the remote seat booking system is implemented in a small computer room.

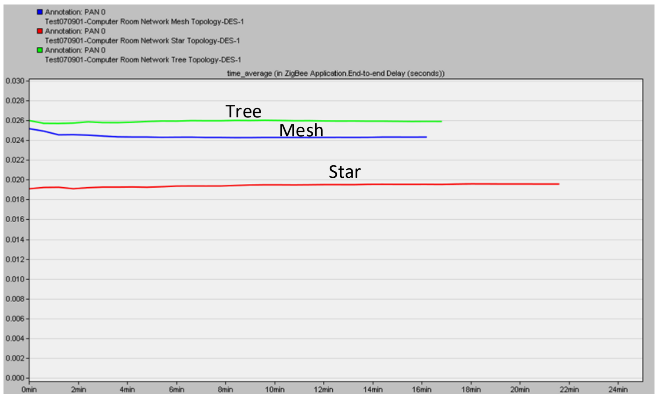

Fig. 4. End-to-end delay of different toplologies in computer room.

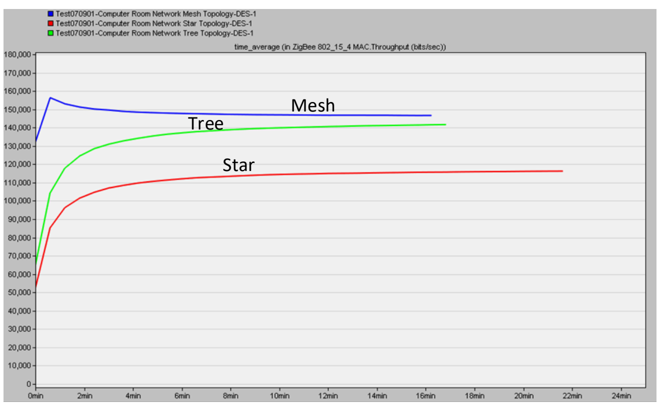

Fig. 5. Throughput of different topologies in the computer room.

The end-to-end delay and throughput comparisons among the three network topologies are shown in Fig. 6 and 8, respectively. On the one hand, similarly to the small-scale network simulation scenario in the computer room, the start network topology achieved the minimum delay compared to the other topologies. Since all end devices communicate directly with their parent node by a single hop, the destination of each device is fixed, and the router discovery, as well as the path searching time, can be saved. Unlike the start topology implementing a larger-scale network where the coordinator would become a bottleneck with performance degradation in end-to-end delay. The tree and star topology achieved similar throughput, which could be ignored in this case, as shown in Fig. 7. The network's throughput implemented using the star topology was around six kbps, 2.2kbps less than that of the tree and mesh topology. Even though the required packet size in this project is very small, and star topology remains the best choice in the service center, similar to the computer room.

Fig. 6. End-to-end delay of different topologies in the service center.

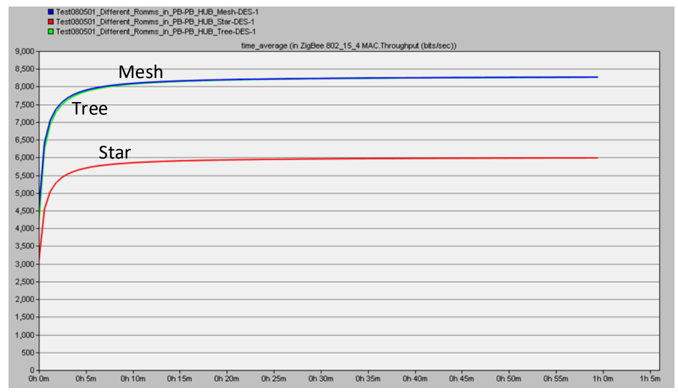

Fig. 7. Throughput of different topologies in the computer room.

The performance comparison of the end-to-end delay for ZigBee WSN implemented across the whole building floor is shown in Fig. 8. Only tree and mesh topologies are used in this scenario since the distance between the source, and destination nodes are large as the floor area is larger than a small self-study or a computer room. Fig. 9 shows the comparison of the throughput using tree and mesh topology across the same floor. As indicated in Fig. 9, the throughput of two network topologies in this scenario is almost identical, and the difference can be neglected. However, as shown in Fig. 8, the tree topology performs better in end-to-end delay. Each device has its routing table for packet transmission; they know their parent node and directly communicate with it.

On the other hand, in the network utilizing the mesh topology, some time is spent searching for the available transmission path through the Ad hoc On-Demand Distance Vector Routing protocol (AODV). Packet collision and network congestion are more likely to happen, if the network utilizing mesh topology is extended to a larger number of nodes [22]. Compared to the mesh topology, the tree topology network saves a massive number of packets used for handshaking; accordingly, the tree topology can achieve efficient data transmission in terms of end-to-end delay without a notable degradation in the throughput. Therefore, the tree topology is preferred for the network implementing the seat booking system across a wide area.

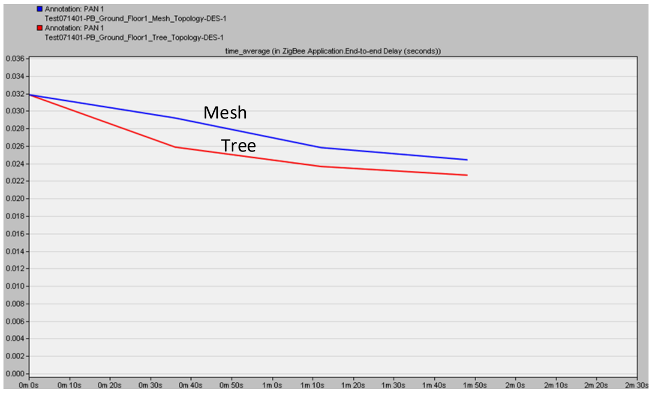

Fig. 8. End-to-end delay of the mesh and tree topologies across the building floor.

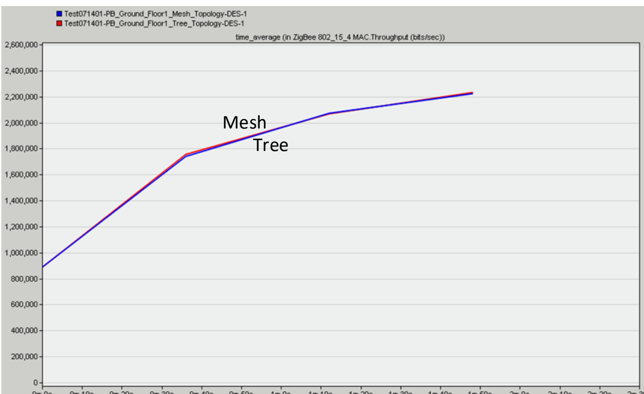

Fig. 9. Throughput of the mesh and tree topologies across the building floor.

VI. Conclusion

This paper presented a project-based network simulation of a proposed seat booking system in a smart campus. The network is based on Zigbee WSN nodes attached to seats in the common study area across the campus. The network was modeled using star, tree, and mesh topologies in the various study and computer rooms of different scales. Network performance of end-to-end delay and global throughputs was tested in different simulation scenarios. The results showed that in the network implemented in a small study area where the distance between the source and destination nodes is less than 20 meters, the star topology is the best choice as it has the minimum delay and can maintain fair throughput, which is enough for the required small packet sizes in the proposed system.

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