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Improving Multi-storey Building Sensor Network with an External Hub

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Abstract—Monitoring and automatic control of building environment is a crucial application of Wireless Sensor Network (WSN) in which maximizing network lifetime is a key challenge. Previous research into the performance of a network in a building environment has been concerned with radio propagation within a single floor. We investigate the link quality distribution to obtain full coverage of signal strength in a four-storey building environment, experimentally. Our results indicate that the transitional region is of particular concern in wireless sensor network since it accommodates high variance unreliable links. The transitional region in a multi-storey building is mainly due to the presence of reinforced concrete slabs at each storey and the façade which obstructs the radio signal and introduces an additional absorption term to the path loss.

Keywords—Wireless sensor networks, radio propagation, building monitoring

I. Introduction

TODAY environmental monitoring is considered as one of the principle application for sensor networks [16]. One of the earliest known civil applications of sensor networks is in ecological habitat monitoring. A team from University of California Berkeley [14], [17], [18] used a wireless sensor network to observe birds on an island, using a base station connected over the web via a satellite communication link. This kind of "unattended" monitoring minimizes disruption to the objects of study by an observer walking around the island to collect data.

A sensor network is a computer network of many, spatially distributed devices using sensors to monitor conditions at different locations, such as temperature, sound, vibration, pressure, motion or pollutants. Usually these devices are small and inexpensive, so that they can be produced and deployed in large numbers, and so their resources in terms of energy, memory, computational speed and bandwidth are severely constrained. Various research problems of sensor networks such as data aggregation or fusion [3], [4], packet size optimisation [15], cluster formation [6], [7], target localisation [21], battery management [5], network protocols [10], [11], [19] are discussed in the literature with respect to crucial energy limitations. Efficient battery management for sensor lifetime [5] and guidelines for efficient and reliable sensor network design is investigated in [8]. Commercial radio technology has advanced and commercial standards such as Bluetooth, developed by the Bluetooth consortium [1], have started to appear. Ad hoc networks have been gaining popularity for military, space, biomedical and manufacturing applications in recent years because their easy deployment and lack of infrastructure requirements. Unlike cellular wireless networks, ad hoc wireless networks do not need any fixed communication infrastructure. Three main networking protocols are known in wireless communications: direct communication, multi-hop communication and clustering. The routes can be single or multi-hop and the nodes which may be heterogeneous and communicate via packet radio. The heterogeneity of the nodes would allow some nodes to be servers and others to be clients. The ability of an ad hoc node to act as a server or service provider will depend on its energy, memory and computational capacities. Each node should estimate its own battery life before committing to a task. Even relaying packets for others may result in deteriorating its own limited battery power, and the node may not accept the task when it is devoted to another important activity. There is a fundamental, incompatible features between computer simulation and experimental evaluation of sensor networks. On one hand, computer simulations provide complete control and transparent into experiments, but, on the other hand, they cannot reproduce, trustworthy, all the parameters that affect a live system [16].

In this paper, we performed experimental study to investigate link quality distribution in sensor network deployment for building environment. This experiment will leverage queries in real sensor network and also will drive development of network architecture. Both man-made hazards such as crime and terrorism as well as natural hazards such as earthquakes, tsunamis and winds can cause damages to building. Sensor networks can be effectively used to reduce the impact of such hazards through early detection. Therefore, monitoring and automatic control of building environment is a crucial application of Wireless Sensor Network (WSN) in which maximizing network lifetime is a key challenge. We have previously investigated the link quality distribution to obtain full coverage of signal strength in a single floor of building environment. Our results confirmed the transitional region is particular concern in wireless sensor network since it accommodates high variance unreliable links. The reason due to this transitional region in inside building environment could be the obstacles including concrete/brick walls, partitions, office furniture and other items affect as additional absorption term to the path loss. We now extend the experimental work to explore the performance of a sensor network that is deployed into a four-storey building with a network hub located at mid-height on an adjacent building. This configuration allows the

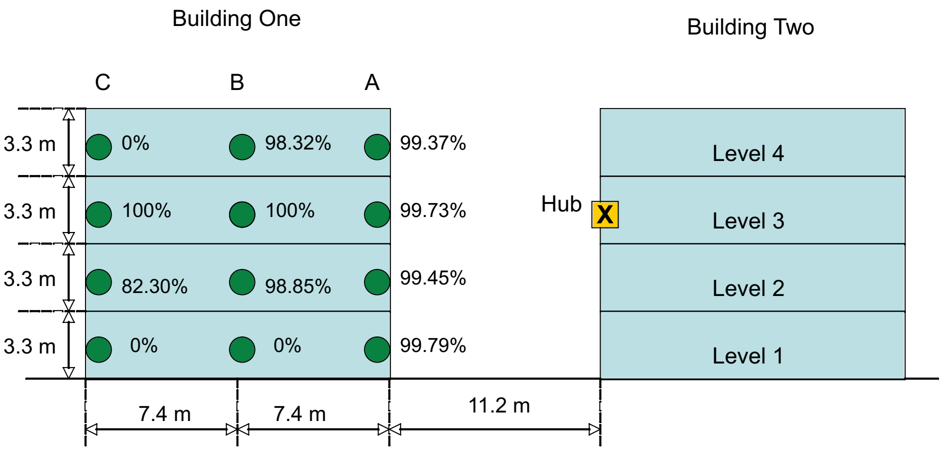

Fig. 1. Deployed area of sensor network (front view) in two, multi-storey, buildings at The University of Melbourne

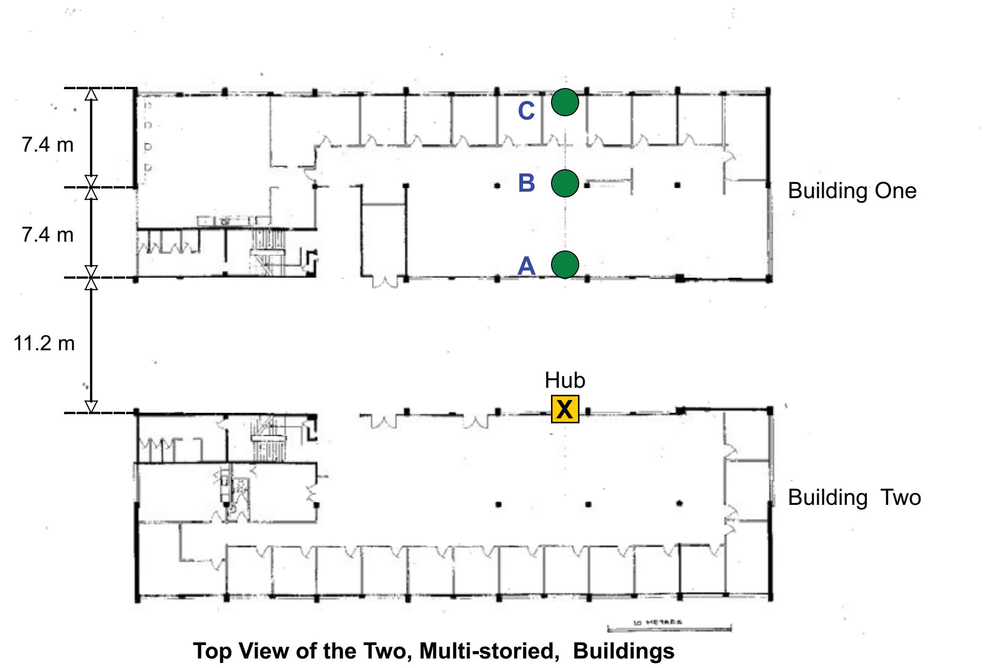

Fig. 2. Deployed area of sensor network (top view) in two, multi-storey, buildings at The University of Melbourne.

network hub to be centrally located and minimize signal loss.

In Section II we explain about wireless link quality and data access rate and in Section III we explain our experiment setup and network configuration. In Section IV, we show experimental results and in Section V we conclude the paper.

II. Wireless Link Quality and Data Access Rate

Several studies [12], [13], [20] have performed experimental studies of link quality in wireless sensor network. There is no realistic model to show how data reception rate vary with the distance. This combine both radio propagation model and radio reception model. It is very clear data from high power transmitters can be successfully received even with simultaneous traffic [12]. However, energy cost for radio transmissions, receptions and idle listening is quite challenging.

It is well known that, if we consider a contour formed by reception at different locations form same transmitter is not regular. The quality of the transmission link distributions with and without power control are extremely depend on environment and and individual hardware differences [12]. For example indoor office environment show poor link quality distribution than free outdoor settings. Swapping transmitter and receiver at same location can change the link quality. As in [12], there is three regions of link quality:

1) *connected region*- high data reception rate ($> 99\%$)
2) *transitional region* - data reception rate is vary, referred to as a gray area
3) *disconnected region* - very low data reception rate

In region 1, data reception rate is highly reliable over time and in region 2, there can be very good link quality although transmissions and receptions antennas (sensor node and the hub) are relatively far away as well as poor link quality, regardless of the relative proximity. In the transition region, there also can be asymmetric radio links (high link quality in one direction and low link quality in other direction). There is high time variation in the link quality in the transition region. The width of the transitional region can be quite significant as a fraction of the connected area. However, in free space the transitional region is minimal but within an office building environment the transitional region could be significant due to the many obstacles, such as furniture, room partitions and concrete/brick walls.

III. Network Configuration and Experiment Setup

Our aim here is to study like quality distribution in a multi-store building environment. We have developed a sensor network for an indoor setting. The network nodes were deployed indoors in a four-storey building (Building One) with reinforced concrete floors, minimal internal partitions and external glass façade. The hub was deployed in an adjacent identical building (Building Two) at the third-storey to investigate the performance of the network within the first building. In this experiment we used iDwaRF sensor nodes [2]. Same radio transceiver ($CYWUSB6935$ 2.4 GHz $DSSS$) with ISM-band was being used in all sensors and the hub. We used standard AAA batteries, however, one can use a permanent supply voltage instead batteries if using fixed locations. The battery voltage is regulated to a constant 3.3 V required for the proper functioning of the $iDwaRF$. During the deployment, we utilised temperature and light sensors. Each sensor node reports data once every 5 seconds. The channel bandwidth is $10-100$ kb/s and each single packet size 17 bytes. A sleeping time of $T_S = 1000$ ms, and a wakeup time of $T_A = 22$ ms, are considered for each sensor node. Active time depends on sampling and radio time. Sampling time is fixed, however, radio time is depend on available channel. Sensor node sense data in every t time period. The hub or base station broadcast channel availability. Sensors listen to channel, if find free channel then transmit data packets to the hub and go to sleep. When hub or base station receives data packet from sensor node it sends acknowledgement to the sensor node. In our experiment, data is not processing locally. Base station just forward data packets to the computer. Computer performs processing of received data, therefore, reduce sensor energy consumption leads to long battery lifetime.

We deployed the sensor network in Buildings One and Two at The University of Melbourne which we consider as a typical example of a multi-storey office building with reinforced concrete floor slabs, internal partitions and a glass and aluminium façade. The layout plan shown in Fig. 1 and Fig. 2 indicates that the target Building consists mainly of internal partitions, which were "permeable" to radio waves and separated by reinforced concrete floor slabs which were "opaque". Previous work [9] on the deployment of building sensor networks has been limited to investigations on the radio propagation in a single storey where the radio signals are radiating laterally. It has been shown that the reinforced concrete slab which separates each storey acts an effective deflector of radio signals and does not allow inter-floor network communications. We now propose to locate a network hub in an adjacent building to provide additional coverage to multiple storeys in a four-storey building. In this configuration, the hub is located at the window of level 3 of Building Two, and the nodes are placed at various locations in all storeys of Building One.

The nodes were programmed to operate in a star network where each node was in direct two-way communication with the Hub in order to determine the efficiency of the bi-directional radio communication. The sensor nodes were deployed at a total of 12 locations (Grid lines A, B, C at levels $1, 2, 3, 4$) for a period of at least 60 minutes at each location, during this preliminary project. The data interval was nominally set at 5 seconds to obtain a sufficient number of readings for each location. No communication was achieved by the nodes in three locations $1-B$, $1-C$ and $4-C$.

IV. Results and Discussion

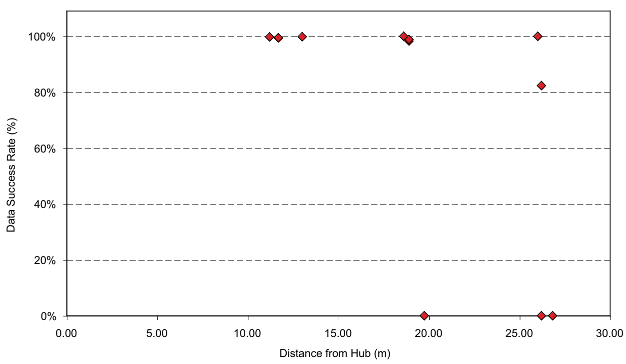

Fig. 3. Experimental values of data success rate of the sensor deployment area at multi-storey building as in Fig. 1 and Fig. 2. Data success rate respect to distance between nodes and the hub or base station.

A. Data Transmission

Table I indicates the reliability of the data transmission by tabulating the expected number of readings from the nodes against the actual data packets received and were post-processed to determine the number of repeated packets. The data indicates that nodes located within the same storey of the Hub all exhibited excellent data transmission rates exceeding 99%. Nodes located either one storey above or below the level of the hub were generally effective with data transmission rates exceeding 98%. The reliability of the node located at the far end of storey 2 dropped to 82% but was still able to provide reliable data communications. A plot of the data communication efficiency against distance in Fig. 3 shows

TABLE I
DATA VALUES

Location	Expected Readings	Received Readings	Retrans-mission	Useful Data	Lost Data	Retrans-mission %	Useful Data %	Lost Data %	Horizontal Distance (m)	Verticle Distance (m)	Distance (m)
4-A	951	951	6	945	6	0.631	99.369	0.631	11.2	3.3	11.7
4-B	951	964	29	935	16	3.049	93.318	1.682	18.6	3.3	18.9
4-C	951	0	-	-	-	-	0	-	26.0	3.3	26.2
3-A	727	726	1	725	2	0.138	99.725	0.275	11.2	0.0	11.2
3-B	727	735	8	727	0	1.100	100.00	0.00	18.6	0.0	18.6
3-C	727	728	1	727	0	0.138	100.00	0.00	26.0	0.0	26.0
2-A	733	733	4	729	4	0.546	99.454	0.546	11.2	3.3	11.7
2-B	694	702	16	689	8	2.305	98.847	1.153	18.6	3.3	18.9
2-C	825	1624	945	679	146	114.55	82.303	17.697	26.0	3.3	26.2
1-A	959	959	2	957	2	0.209	99.791	0.209	11.2	6.6	13.0
1-B	959	0	-	-	-	-	0.000	-	18.6	6.6	19.7
1-C	959	0	-	-	-	-	0.000	-	26.0	6.6	26.8

that the data rate drops significantly beyond a difference of two-storeys between the hub and nodes. Our previous results [9] clearly illustrated three regions indicated by [12]. The transitional region (nodes located at the far end of building One) is particular concern in wireless sensor network since it accommodates high variance unreliable links. The network coverage area is exceedingly affected by the presence of the reinforced concrete slab. Moreover, radio waves tend to be reflected or diffracted by conductive objects and rarely penetrate them. The reason due to this transitional region in inside building environment could be the obstacles including the reinforced concrete elements, partitions, furniture and other items affect as additional absorption term to the path loss.

V. Conclusion

We have investigated the link quality distribution to obtain full coverage of signal strength in a four-storey building, experimentally. Our results confirmed that an external hub can overcome the obstruction between floors and improve the performance of the radio network. Moreover, our results show transitional region is small for multi-storey buildings and areas obstructed by the reinforced concrete slab are disconnected from the network. The reason due to this disconnected region in an indoor building environment is the obstruction posed by the presence of the reinforced concrete slabs which separates each storey in the building. The internal partitions and glass façade affect the radio signal propagation to a lesser extent and may be included as additional absorption terms to the path loss.

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