Poster Abstract: On the feasibility of an IoT Multi-Radio Architecture for Smart Buildings

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ABSTRACT

Smart buildings are rapidly expanding to asset management, crowd-sensing, localization, and human identification. These applications exploit low-powered IoT devices. These devices are untethered from building's power and communication infrastructure, reducing deployment costs while trying to retrofit into the existing building stock. Low-power radios (e.g. 802.15.4) have limited transmission range. This limitation is amplified by the fact that large commercial buildings expand multiple floors, have different non-RF friendly materials (e.g. metal structures, firewalls, etc.), and have occupants' movement that further affects the communication range.

Low-Power Wide Area Networking technologies (e.g. LoRaWAN) trade-off throughput for extended communication range compared to 802.15.4, with similar energy profiles. In this work, we propose to use a multi-radio architecture to explore the trade-offs between throughput and latency to achieve resilient communications. We do an analytic performance analysis to identify the feasibility and necessity of an IoT multi-radio architecture for smart buildings. We identify three crucial parameters namely, distance, throughput, traffic patterns, and their ranges at which multi-radio architecture works efficiently in smart building scenarios.

CCS CONCEPTS

• **Computer systems organization** → *Sensor networks*; • **Networks** → *Network performance analysis*; *Network design principles*.

KEYWORDS

Smart Buildings, IoT, Multi-radio, LoRa, ZigBee, Analysis.

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1 INTRODUCTION

Emerging smart building applications like asset management, crowd sensing, surveillance, human identification, and localization [2, 5] employ low-powered IoT devices. These devices are untethered from the building infrastructure. These battery-operated IoT nodes demand longer lifetime to avoid frequent battery replacements. Their transmission range is limited by low-power RF transceivers (e.g. 802.15.4/Zigbee). There are two issues in buildings that affect the deployment of short-range communication radios. First, buildings are made of different materials like steel, reinforced metals, and wood that hinders radio communications. Second, the dynamic occupancy pattern of the occupants' affect system performance. Some applications like occupancy detection, and localization experiences a spike in data traffic due to crowd influxes. Densely deployed multi-hop network overcomes the above two issues.

Recently, Low-Powered Wide Area Networking technologies (e.g. LoRaWAN) have been developed. These radios trade-off data rate for extended communication range when compared to 802.15.4, with similar energy use profiles. Considering these new radios, we propose to design, implement and evaluate a new multi-radio architecture to alleviate the above challenges and to explore the trade-offs between throughput, latency, and power consumption in smart building scenarios. On the one hand, LoRa is a low-frequency radio working in 915MHz, which can penetrate various hard structures of the building and can reach the gateway in a single hop. On the other hand, Zigbee is a comparatively high-frequency radio working in 2.4GHz, providing an order of magnitude higher data rate than LoRa, but communicating at a lower range in multi-hops. Zigbee can easily handle the influx of crowd movement because of higher data rate at lower ranges. We propose to use both radios in the same node and chose one at the time of transmission. In this work we (i) analyze the feasibility of multi-radio architecture for smart building systems, (ii) identify different parameters and their ranges required for efficient functioning of multi-radio architecture.

2 ANALYTIC FEASIBILITY ANALYSIS

Topology setup. A simple line topology is used for this analysis because a packet takes a straight line path to reach the gateway in any topology. One gateway and fifteen nodes are placed at a distance of 100m from each other in free space. Packets of size 29 bytes are generated according to a Poisson process at the rate of λ=0.2 packets/second. Each node has both LoRa and Zigbee radios. All generated packets are destined to the gateway. LoRa gateway is capable of receiving eight packets concurrently [4]. LoRa nodes transmit in a 500KHz channel to provide faster data rate. Each node placed within 800m from the gateway is tuned to one of the eight different channels the gateway is listening to and transmit at SF7. Each node placed between 800m to 1200m transmit at SF8, tuned to different channels that has only one SF7 node. Nodes placed between 1200m to 1500m transmit at SF9, tuned to different channels that has either a SF7 or a SF8 node.

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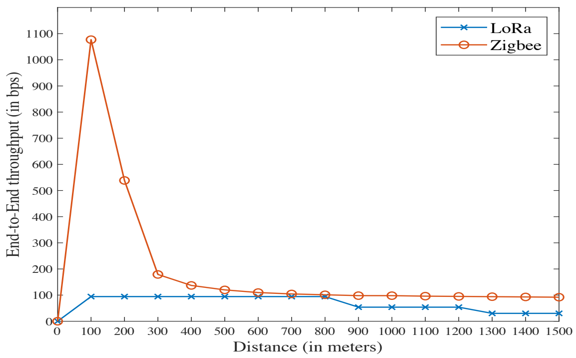

Figure 1: End-to-End throughput calculated as the function of distance. LoRa and Zigbee becomes competitive from 300m to 800m. Hence, we need a mechanism to choose between LoRa and Zigbee at the time of transmissions.

Calculations. LoRa uses ALOHA where nodes can transmit at their will. Packets are transmitted at the Poisson rate λ packets/second. Assuming that each packet occupies the channel for τ seconds. Then the normalized traffic G = $\lambda \times \tau$. Then the normalized channel throughput is given by S = $\lambda \times \tau$. A packet reception is successful only if there is no other transmission in the interval $[-\tau, \tau]$. Since Poisson process defines all the transmission times, the probability that two packets won't collide is $e^{-2\lambda.\tau} = e^{-2G}$ packets [1]. Therefore the throughput of LoRa is given by $S = Ge^{-2G}$.

The multi-hop Zigbee network employs CSMA. Each node schedule packets to its neighbors using a Poisson point process. By assuming independent Poisson process, relaying and queuing delays can be ignored. This network can be modelled using a Continuous Time Markov Chain with set of nodes transmitting at any time instant as the states [3]. Let i be a node, N_i be the set of all neighbors of i. Let g_{ij} and s_{ij} be the scheduled and desired packet rates when a packet is transmitted from node i to j. Let P(A) be the probability that all nodes in set A are silent at any given instant of time. A node can transmit only when its neighbors are silent. This gives us

$$\frac{s_{ij}}{g_{ij}} = P(N_i \cup N_j) \tag{1}$$

The network state for given g_{ij} is defined by the set of nodes D that are in transmitting state. Using steady state probabilities and global balance equations P(A) can be given as

$$P(A) = \frac{SP(A^c)}{SP(V)} \tag{2}$$

where SP is the sum-of-products, A^c is the set of nodes that are not in set A, SP(V) is the sum-of-products of all the nodes in the network. (See [3] for more details). Applying equation 2 in 1 gives,

$$\frac{s_{ij}}{g_{ij}} = \frac{SP(([(N_i \cup N_j)])^c)}{SP(V)}, j \in N_i \tag{3}$$

This equation 3 can be written for all the transmit/receive pairs in the network to form a system of linear equations that can be solved iteratively for s_{ij} with given g_{ij} giving end-to-end throughput.

2.1 Result analysis

Throughput. The end-to-end throughput calculated as the function of distance is depicted in Figure 1. Zigbee wins until 300m because Zigbee's available data rate is an order of magnitude higher than LoRa. The reason for a drastic difference in throughput between LoRa and Zigbee at 100m is that only one node is transmitting without any contention. A considerable drop in Zigbee throughput is seen from 100m-300m because it uses a single channel with three contenders. CSMA mechanism blocks two other links from transmitting to avoid collisions, allowing only 1/3 of links to transmit at any given time until 300m. LoRa has a steady throughput until 800m because each end-node is tuned to eight different available channels exploiting the concurrent reception ability of the LoRa gateway. Zigbee throughput reduces gradually from 300m-800m because Zigbee uses single-channel and the number of contenders increases, increasing the blocking delay of CSMA at each hop. ***From 300m to 800m, LoRa and Zigbee provide competitive throughput.*** From 900m-1500m, Zigbee throughput trivially decreases as the blocking delay of CSMA stays almost steady after 900m. LoRa's throughput drastically reduces at 900m because LoRa radios are set to SF8 after 900m until 1200m which reduces the available data rate. At 1300m, a further decrease in throughput is seen as LoRa radios are set to SF9 which further reduces the available bandwidth.

Delay. Throughput indirectly shows the delay of LoRa and Zigbee because, when the delay is higher, throughput will decrease. Figure 1 shows a major decrease in Zigbee throughput from 100m to 300m indicating the increase in CSMA blocking delay. LoRa node is tuned to a different channel until 800m, so zero contention gives zero delay. From 300 to 500m, it is seen from Figure 1 that Zigbee throughput decreases indicating the increase in delay. Also, after 800m, each of the SF8 and SF9 nodes is tuned to a channel which an SF7 node is using. Given very low packet rates, the probability of collision and the LoRa gateway channel saturation, (i.e) the time instant at which all the eight channels of the LoRa gateway is busy, is negligible. Zigbee has trivial delay after 800m.

3 CONCLUSION AND FUTURE WORK

In this work, we enumerate the challenges of emerging smart building applications and argue that multi-radio architecture can overcome these challenges. We do an analytic performance analysis to show the feasibility of an IoT multi-radio architecture for smart building scenarios. This analysis also identifies that at low packet rates, like 0.2 packets/second, LoRa and Zigbee can provide competitive performance at 300-800m from the gateway. In future, we plan to simulate this setup to identify more parameters and their ranges to develop a radio-switching algorithm that chooses the efficient radio between LoRa and Zigbee at the time of transmission to transmit a message based on various factors like application needs, urgency of the message, traffic pattern, link quality, and more.

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