Poster Abstract: The Purpose and Benefit of Segmenting a Multi-Transmitter Network

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Abstract—**In a multi-transmiter network, multiple wireless nodes transmit data at the same time. If these transmissions are timed close enough to each other, they interfere non-destructively and can be correctly decoded. Systems such as CX, Glossy, and LWB use this principle to achieve efficient and reliable network-wide synchronization or communication. In practice, many wireless sensor network deployments are "patchy", i.e., a few widely-spread areas are densely instrumented. While prior work in multi-transmitter networks relied on a single, globally-coordinated network, intuition tells us that subdividing the network will make it easier and more energy-efficient to coordinate schedules. In this work, we show how multi-transmitter networking can be applied to segmented networks and evaluate its effect on energy consumption and packet delivery rates.**

I. INTRODUCTION

Glossy [1], Low-power Wireless Bus (LWB) [2], and CX [3] are examples of an emerging family of multihop wireless sensor network (WSN) communication protocols which we refer to as *multi-transmitter networking*. These systems leverage a combination of non-destructive concurrent transmissions and radio capture effect to perform fast network floods that reach all nodes with high probability: every node receiving a packet rebroadcasts it at precisely the same time, reducing destructive interference. In addition to the high yield, good throughput, and low energy consumption demonstrated in LWB, these methods require little routing state to work. This makes them suitable for networks with high degrees of node mobility, and may help in challenging environments where existing routing methods struggle to find high quality links. These systems rely on a single globally-coordinated TDMA schedule to prevent conflict and to enable duty-cycling.

In practice, many WSN deployments for environmental monitoring consist of a set of densely-instrumented patches. Each such patch comprises multiple *leaf* nodes (which measure their environment) and one *router* node (which enables inter-patch communication). Many seminal sensor network deployments have employed this network architecture in some form. In this work, we wish to adapt the globally-coordinated multi-transmitter networking approach to one that is well-suited to this common deployment pattern.

In patchy networks, most nodes are leaves. Adding a leaf to the network adds both coordination overhead (in terms of discovering that node and assigning it time in the schedule) and forwarding load to other devices in the network. Our goal is to restrict this impact to just the patch where the new node was added. Each patch is headed by a router, which is responsible for autonomously retrieving the data from its patch. These routers work together to transfer their collected data to a central collection point. In this work, we experimentally verify and quantify the reduced energy cost at leaf nodes and added energy cost at router nodes due to a patchy organization compared to a flat network.

II. CX: A MULTI-TRANSMITTER NETWORK

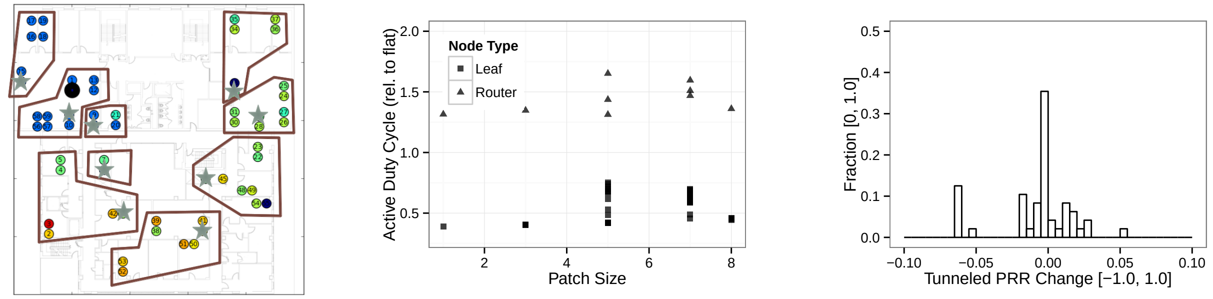
CX is an example of a multi-transmitter network system [3]. In CX, all communication takes place in the form of multi-transmitter floods. Through the use of a hop counter in each packet, nodes learn their relative distances to each other. The hop count information allows nodes to estimate whether they are between a source and destination for a given transfer. These measurements are the basis for our forwarder-selection method, which keeps nodes between the source and destination active while allowing the rest of the network to sleep.

Results from our 66-node indoor testbed show that forwarder-selection reduces duty cycle by 30% on average over simple concurrent flooding while maintaining an average packet reception ratio (PRR) of 99.4%. In the same setting, the average node throughput increases by 49% over simple flooding by using the collected distance information to tighten inter-packet spacing.

III. SEGMENTING MULTI-TRANSMITTER NETWORKS

We subdivide the full network into multiple patches at deployment time. The nodes in different patches are assigned different radio channels through the use of a Graphical User Interface (GUI) tool based on the user's knowledge of how the nodes are physically deployed. We designate some nodes as leaves and designate others as routers, where routers independently collect data from the leaves in their patch. A basestation node periodically downloads the collected data from each router while the leaves keep their radios off to save energy. We use the technique of CXFS [3] to perform each of these data collection steps reliably and efficiently.

Figure 1a shows an example of such a network. Each download, whether from leaves to a router or from routers to a basestation, follows the same basic pattern.



(a) Segmented 50 m x 50 m indoor testbed. Stars mark router nodes, and the black circle marks the ultimate data sink.

(b) Duty cycle increases at leaf with larger patches. 1.0 on the Y-axis indicates no change, higher values indicate worse duty cycle under segmentation than in a flat network.

(c) End-to-end PRR changes for nodes under segmentation.

Fig. 1: Testbed layout and experiment results.

All nodes use Low-Power Probing [4] to coordinate their wake-up/sleep cycles. Once a network segment (e.g. basestation and all routers or a single router and the leaves in its patch) is active, the download proceeds in a series of *slots*, each of which grants exclusive access to a single source node for a period of time (on the order of seconds). The sink sends a Slot Assignment message to one of its immediate neighbors, which responds with a Status message. This Status message informs the sink of the assignee's one-hop neighborhood and carries the necessary information to perform forwarder selection. This allows the sink to discover the members of its network segment. During its slot, a node sends any outstanding data it may have and ends with a message indicating whether or not it still has data pending. When the sink determines that no more nodes have outstanding data, it stops assigning slots and the network segment returns to the idle state.

By assigning each patch to a separate radio channel, we allow these collections to take place in parallel and without interference. Routers perform a download from their patch immediately following a download by the basestation.

IV. EXPERIMENT SETUP

We implemented segmented CX on a CC430-based platform [5] on our indoor testbed. Prior to segmenting the network, the mean end-to-end PRR is above 99.5% from leaf to root (with and without forwarder selection), while the root to leaf PRR is 98.7%. This low PRR appears to be due to poor connectivity at a single node. We divided our testbed into 9 distinct patches with 1-8 leaf nodes in each patch.

The sink collects 75 packets per download, with 100-byte payloads, which is roughly equivalent to the daily data rate for our target application (8 sensors per node, 2-byte samples, 10-minute sampling rate, and associated timing information and metadata). Transmission power was set to -6 dBm at all nodes. Our platform can be assembled with a radio amplifier which may be used to extend the distance between patches.

V. RESULTS

Figure 1b plots the duty cycle changes in the network. The average leaf duty cycle drop is 56% of its single-tier level when they are grouped into patches. The improvement in leaf node duty cycle is not free. While routers enjoy the same short downloads that the leaves in their patch do, they also have to retransmit all of this data to the root and suffer an additional wakeup. Their duty cycle is 50% higher than it is in a single-tier network, on average. That being said, the total energy consumption of the network decreases under segmentation, consuming only 70.8% as much as the flat network.

The end-to-end packet reception ratio for leaf nodes may change when the network is segmented. Figure 1c shows the distribution of the changes in PRR experienced by the leaf nodes when moving from a flat network to a tiered network. The average packet reception ratio drops to 96.91%, primarily due to the poor router-to-root PRR of a single router. 22 out of the 57 leaf nodes see improvements ranging up to 3.5%. This can occur if their router has a good PRR to the root, and their in-patch PRR is better than their flat-network PRR.

VI. CONCLUSIONS

In this work, we adapt multi-transmitter networks to take advantage of the patchy layout present in many wireless sensor network deployments. We found that segmenting a multi-transmitter networks into patches results in significant energy savings for the leaves at the expense of higher energy expenditure on the routers. Sending packets through the routers in a patchy networks is limited by the achievable PRR to the quality of connectivity between the routers and the downstream nodes.

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