Demo Abstract: Enabling Inter-SNOW Concurrent P2P Communications

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***Abstract*—SNOW (Sensor Network Over White Spaces) has evolved as an enabling technology for Internet-of-Things (IoT) applications. To meet the future IoT demands, multiple SNOW networks will require to interact with each other, and thus demanding a scalable seamless integration between them. In this demonstration, we showcase seamless concurrent peer-to-peer (P2P) communications between multiple SNOW networks.**

I. SNOW Overview

SNOW [1], [2] is an asynchronous, long range, low power WSN platform that operates over TV white spaces. A SNOW node has a single half-duplex narrowband radio. Due to long transmission (Tx) range, the nodes are directly connected to a base station (BS) and vice versa. SNOW thus forms a star topology. The BS determines white spaces in the area by accessing a cloud-hosted database through the Internet. The nodes are power constrained and do not do spectrum sensing or cloud access. The BS uses a wide channel split into orthogonal subcarriers. As shown in Figure 1, the BS uses two radios, both operating on the same spectrum – one for only transmission (called ***Tx radio***), and the other for only reception (called ***Rx radio***). Such a dual-radio of the BS allows concurrent bi-directional communication in SNOW.

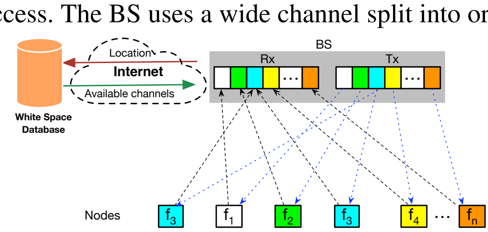

Fig. 1. SNOW with dual radio BS and subcarriers

SNOW Physical Layer: The physical layer (PHY) of SNOW uses a **D**istributed implementation of **OFDM** (Orthogonal Frequency Division Multiplexing) for multi-user access, called **D-OFDM**. The narrowband orthogonal subcarriers of the BS's wide spectrum carry parallel data streams to/from the distributed nodes from/to the BS as D-OFDM. Each node transmits and receives on its assigned subcarrier. Each subcarrier is modulated using Binary Phase Shift Keying (BPSK). A subcarrier bandwidth can be chosen as low as 100kHz, 200kHz, or 400kHz depending on the packet size and expected bit rate. Unlike the recent adoption of OFDM for multiple access in WiMAX and LTE using multiple antennas [3], [4], [5], D-OFDM enables multiple packet receptions using a single antenna which are transmitted asynchronously from different nodes. It also enables different data transmissions to different nodes through a single transmission using a single antenna. If the BS spectrum is split into n subcarriers, it can simultaneously receive/send from/to n nodes. The BS can also exploit fragmented white spaces.

SNOW Media Access Control (MAC) Layer: The BS splits white space spectrum into n overlapping orthogonal subcarriers – $f_1, f_2, \cdots, f_n$ – each of equal width. Each node is assigned one subcarrier. When the number of nodes is no greater than the number of subcarriers, every node is assigned a unique subcarrier. Otherwise, a subcarrier is shared by more than one node. The subcarrier allocation is done by the BS. The nodes in SNOW use a lightweight CSMA/CA protocol for transmission that uses a static interval for random back-off like the one used in TinyOS [6] . The nodes can autonomously transmit, remain in receive (Rx) mode, or sleep. Since D-OFDM allows handling asynchronous Tx and Rx, the link layer can send acknowledgment (ACK) for any transmission in either direction. As shown in Figure 1, both radios of the BS use the same spectrum and subcarriers - the subcarriers in the Rx radio are for receiving while those in the Tx radio are for transmitting.

II. System Model

We consider many coexisting SNOWs are under the same manegement/control and need to coordinate among themselves for extended coverage in a wide area or hosting different applications. As such, we consider an inter-SNOW network as a **SNOW-tree**. Only the **root** of the tree is connected to the white space database. Each cluster is a star topology SNOW. All BSs are connected through white space. Every BS is assumed to know the location of its operating area (its location and the locations of its nodes. Localization is not the focus of our work and can be achieved through manual configuration or some existing WSN localization technique such as those based on ultrasonic sensors or other sensing modalities [7]. The root BS gets the location information of all BSs and finds the white space channels for all SNOWs. It also knows the topology of the tree and allocates the spectrum among all SNOWs.

III. Concurrent Inter-SNOW Communications

Here we describe inter-SNOW communication technique to enable seamless integration of the SNOWs for scalability

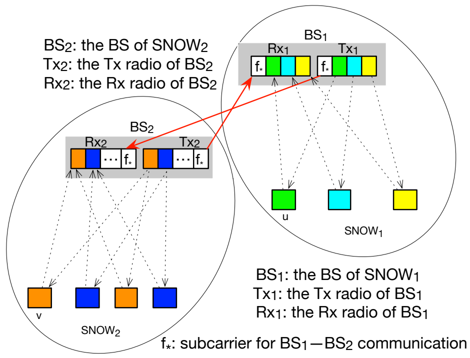

Fig. 2. Inter-SNOW communication

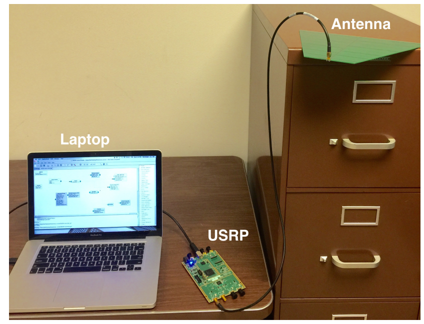

Fig. 3. A SNOW-tree

by exploiting the PHY design of SNOW. To explain this we consider *peer-to-peer* (P2P) communication between two SNOWs. That is, one node in a SNOW wants or needs to communicate with a node in another SNOW.

P2P Communication: For P2P communication across SNOWs, a node first sends its packet to its BS. The BS will then route to the destination SNOW's BS along the path given by the tree which in turn will forward to the destination node. Hence, the first **question** is *"How do two neighboring BSs exchange packets without interrupting their communication with their own nodes?"* Let us consider SNOW_1 and SNOW_2 as two neighboring SNOWs in Figure 2 which will communicate with each other. We allocate a special subcarrier from both of their spectrum (i.e., a common subcarrier among the two BSs) that will be used for communication between these two BSs. This subcarrier will not be used for any other purpose. In the figure, f_* is shown as that special subcarrier. D-OFDM allows us to encode any data on any subcarrier while the radio is transmitting. Thus the SNOW PHY will allow us to encode any time on any number of subcarriers and transmit. Exploiting this important feature of the SNOW PHY, Tx_1 radio will encode the packet on the subcarrier f_* which is used for BS_1–BS_2 communication in Figure 2. If there are pending ACKs for its own nodes, they can also be encoded in their respective subcarriers. Then Tx_1 radio makes a single transmission. Rx_2 will receive it on subcarrier f_* while the nodes of SNOW_1 will receive on their designated subcarriers. BS_2 can receive from BS_1 in the same way. They can similarly forward to next neighboring SNOWs. Thus both inter-SNOW and intra-SNOW communications can happen in parallel. Following are the several issues and our techniques to address those to enable such communication.

Collision in BS-BS Communication: Using one subcarrier for BS_1–BS_2 communication, BS_1 and BS_2 cannot simultaneously transmit to each other. When Tx_1 transmits on f_*, there is high energy on f_* at Rx_1. The similar is the case when Tx_2 transmits. If they start transmitting simultaneously, both packets will be lost. A straightforward solution is to use two different subcarriers for $\text{Tx}_1 \rightarrow \text{Rx}_2$ and $\text{Tx}_2 \rightarrow \text{Rx}_1$ transmission. However, using two subcarriers dedicated for this may result in their underutilization and hinder scalability. Hence, we use a single subcarrier for BS_1–BS_2 communication and adopt random backoff within a fixed interval rule for this special subcarrier. That is, if BS-BS communication collides, they make random backoff after which they retry transmission.

Dealing with Sleep/Wake up: When a node u from SNOW_1 wants to send a packet to a node v in SNOW_2, it first makes the transmission to BS_1 which then sends to BS_2 (Figure 2). When BS_2 attempts to transmit to v, it can be sleeping which BS_2 has no knowledge of. To handle this, we adopt a periodic beacon that the BS of each SNOW sends to its nodes. The nodes are aware of the period of beacon. All nodes in a BS that are participating in P2P communication wake up for beacon. Thus, v will wake up for beacon as it participates in P2P communication. BS_2 will encode v's message on the subcarrier used by v in the beacon. Thus, v can receive the message from the beacon of BS_2.

IV. Implementation

We have built this demo on GNU Radio [8] using USRP [9] radio front-ends. GNU Radio is a toolkit for software defined radios and digital signal processing. Typically, USRP devices can operate between 70MHz - 6GHz of spectrum. Figure 3 shows a part of our setup.

V. Conclusions

LPWANs represent a key enabling technology for IoT that offer long communication range at low power. While many competing LPWAN technologies have been developed recently, they still face limitations in meeting scalability and covering much wider area, thus making their adoption challenging for future IoT applications, specially in infrastructure-limited rural areas. Through the demonstration of seamless inter-SNOW parallel P2P communications, we showed that SNOW architecture can host future IoT applications.

References

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