論 文 の 内 容 の 要 旨

論文題目　Leveraging Concurrent Transmission for Efficient Mesh LoRa Networks
（同時送信型フラッディングを用いた高効率メッシュLoRa
ネットワークに関する研究）

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LoRa is a Low-Power Wide-Area network (LPWAN) standard and has garnered wide interests in the current Internet of Things (IoT) era. By adopting Chirp Spreading Spectrum (CSS) technology, LoRa provides a remarkably wide coverage as compared to that of the conventional standardized wireless radio frequency technologies. Recently, to further extend the coverage by utilizing multiple relays and improve the network capacity by using different Spreading Factors (SF), a multi-hop LoRa network has become a promising technology for both academic studies and industrial applications. On the other hand, Concurrent Transmission (CT) flooding, a highly efficient multi-hop protocol which provides ultra-fast back-to-back relaying by allowing synchronized packet collision, will be a good candidate for the multi-hop LoRa network.

This thesis aims to construct an efficient mesh LoRa network by leveraging CT. Towards this, we first verify whether the LoRa receiver can endure co-technology interference (i.e., interference from LoRa packets) to realize a CT-based mesh LoRa network, namely CT-LoRa. Second, to improve the capacity of a mesh CT-LoRa network, our approach is to attempt to off-load the data traffic into several subnets by utilizing this multiple-access dimension. Each subnet rooted at a sink node is allocated a specific SF on the basis of network clustering. This enables constructing multiple CT-LoRa subnets to transmit packets in parallel in the entire space, namely parallel CT-LoRa, to become feasible. The main contributions of this thesis are twofold.

LoRa Receiver Performance under CT : In CT-LoRa, we have evaluated the receiver performance under synchronized packet collisions from LoRa signals using the same SF (Same-SF Interference). The evaluation results show that, under identical condition, larger SFs lead to better performance under same-SF interference. Also, in practical scenarios, LoRa on each SF can benefit from the multi-hop CT flooding. On the other hand, when SFs are utilized as a dimension for multiple access, we have evaluated LoRa receiver performance under the interference with different SFs (Different-SF interference) to verify the orthogonality between each other. The evaluation results show that the SFs are not fully orthogonal by using both simulations and real-chip experiments. Although the LoRa receiver has a tolerance in front of co-technology interference, the required signal-to-interference ratio (SIR) differs for different SFs for successful data transmission. Specifically, smaller SFs (i.e., SF7 and SF8) are strongly affected by co-technology interference, while larger SFs show stronger immunity to interference and have fewer impacts on LoRa signals using different SFs.

SF Allocation for Parallel CT-LoRa : We proposed a tree-based SF clustering algorithm (TSCA) for realizing parallel transmission with a balanced SF allocation in a multi-hop CT-LoRa network. We consider the original network where all nodes keep using the fastest data rate (SF7) in the initial state. Moreover, given a well-connected tree using SF7, which is the shortest path from the relay nodes to the root node, the algorithm removes a certain number of nodes to generate spanning sub-trees using larger SFs. Specifically, as compared to a single-hop topology for which the connectivity check is unnecessary, the connectivity is confirmed when conducting SF allocation. To balance the data loads between all sub-trees, we employ a constraint rule with not only the data rate but also the tree height to limit the number of nodes in each sub-tree. The tree height is also considered when we first estimate the capacity of each SF by using the maximum hop count on each sub-tree. Furthermore, the TSCA is designed such that the algorithm updates the constraint rule iteratively based on the real hop count of the current topology. To reduce the hop count of each sub-tree, we attempt to remove the nodes farthest away from the root and using SF7, by inserting them into a sub-tree with a larger SF and with a lower height. More specifically, we use the Bottom-up Breadth-First-Search (BBFS) algorithm to determine the order in which extraction occurs and the Top-down Breadth-First-Search (TBFS) algorithm for the insertion. Moreover, the balance between the sub-trees is maintained by inserting the removed nodes into a sub-tree that will have Minimal Airtime (MAT) after the insertion.