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GENETIC SIMULATED ANNEALING BASED GROUP MANAGEMENT SOLUTION FOR MULTIPLE VENDORS IN LOW-POWER AND LOSSY NETWORKS

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ABSTRACT

Techniques are described herein to transform logical group traffic into a combination of broadcast and unicast messages rather than flood of broadcast messages. These techniques limit redundant traffic to manage logical group traffic over Wireless Mesh Networks (WMNs).

DETAILED DESCRIPTION

The Wireless Smart Ubiquitous Networks (Wi-SUN) Alliance provides connectivity to service providers, utilities, municipalities/local government and other enterprises by enabling inter-operable, multi-service, and secure Wireless Mesh Networks (WMNs). Wi-SUN can be used for large-scale outdoor Internet of Thing (IoT) wireless communication networks in a wide range of applications. Customers prefer to buy products from multiple vendors based on open standards in order to reduce cost and risk in practice.

As shown in Figure 1 below, a customer may build a Wi-SUN based WMN with multiple vendors. The nodes provided by the vendors are typically compatible because the vendors have all adopted Wi-SUN protocols. However, they sometimes have difficulties when running platform dependent management operations (e.g. Firmware Upgrading (FU)).

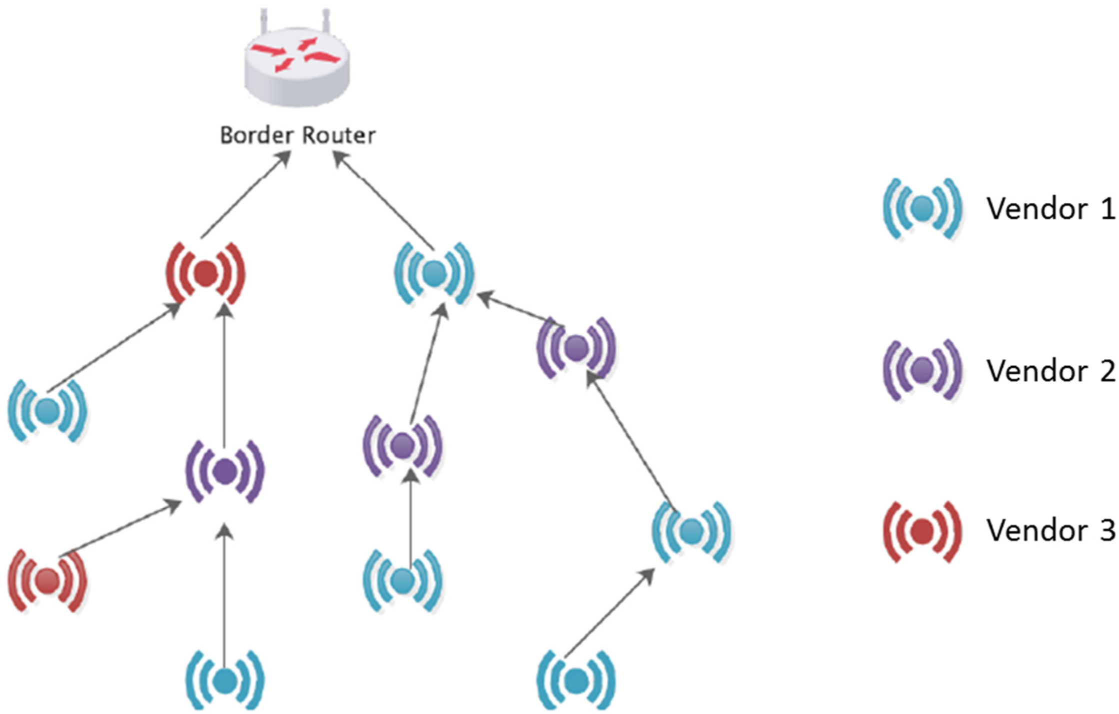

Figure 1

Currently, broadcast propagation is used to upgrade firmware for all nodes. However, this may be not suitable for hybrid networks that consist of nodes provided by multiple vendors. As illustrated in Figure 2 below, upgrading firmware for just 20% nodes using broadcast propagation wastes a disproportionate amount of bandwidth resource because 80% of nodes do not need the FU. In this example, the customer wants to upgrade only Vendor 3 nodes. Leveraging broadcast propagation will waste both energy and bandwidth consumption.

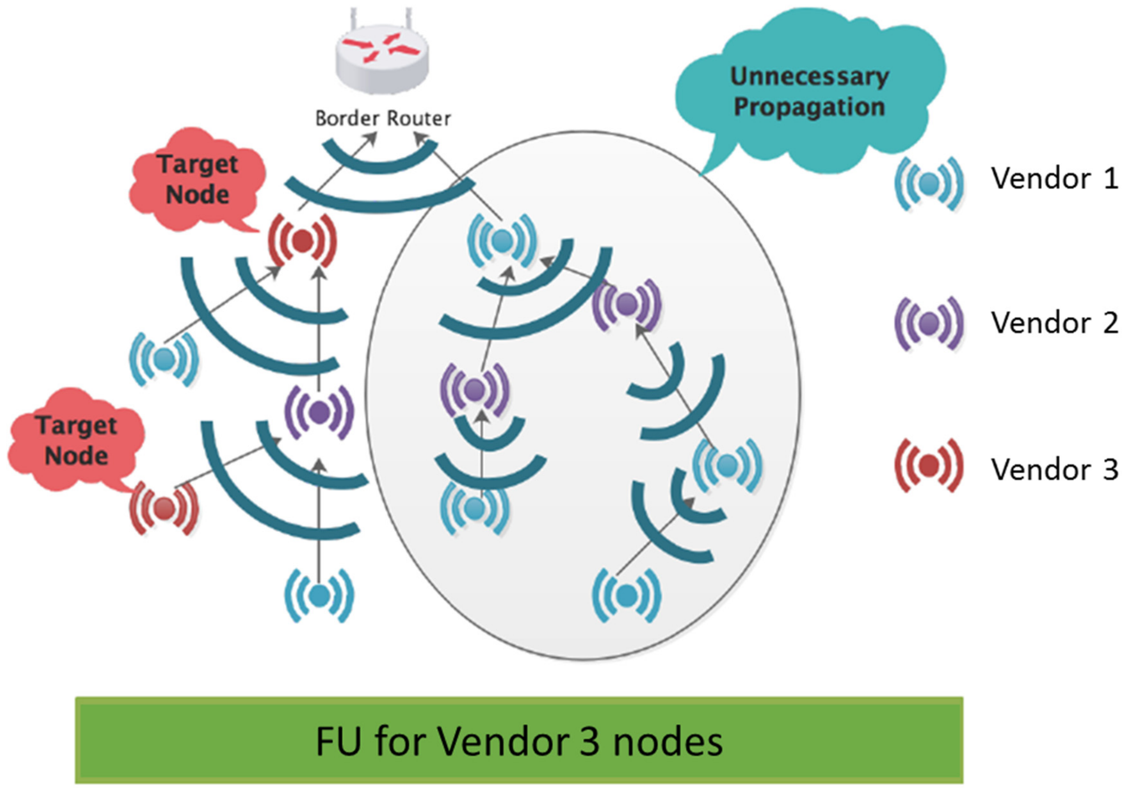

Figure 2

In order to make full use of bandwidth while avoiding collisions among wireless neighbors, WMN adopts frequency hopping technology. As illustrated in Figure 3 below, every node has a unique channel sequence which is used for unicast, so that its neighbors will not affect its communication because they are on different channels during the same time slot. The nodes also have a common broadcast frequency hopping which overlays the unicast channel plan. This may reduce traffic while all nodes are sharing information in a Personal Area Network (PAN).

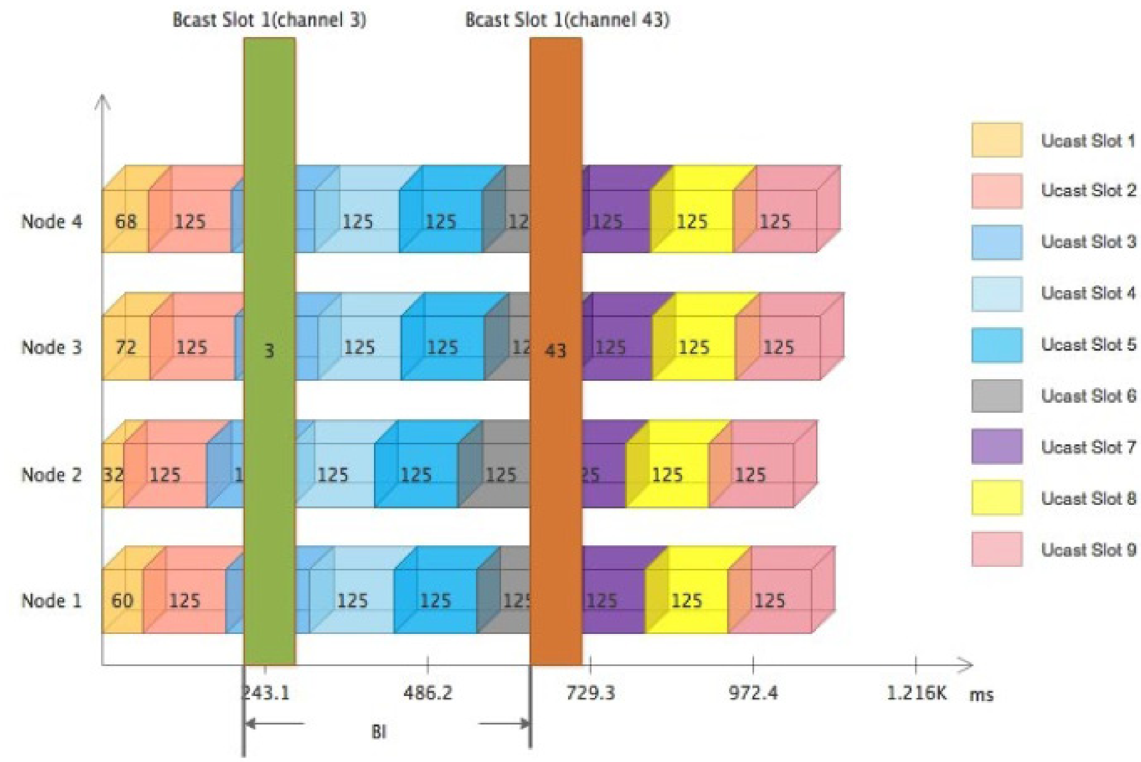

Figure 3

Therefore, broadcasting every packet will take too much time. For example, as illustrated in Figure 4 below, if one broadcast slot (e.g., 125 ms) carries 1KBytes of packets, the entire file is 600KBytes, and there are intervals of three broadcast slots between two broadcast propagation instances, the entire transmission would take 300 seconds. Unicast propagation would take 100 seconds. Because broadcast uses the same channel for all nodes, there are more conflicts. Rather than using slow and unstable broadcast links for FU, unicast propagation is preferable where possible. Many unwanted nodes that are involved in group management must also be avoided, to avoid wasting traffic in unicast.

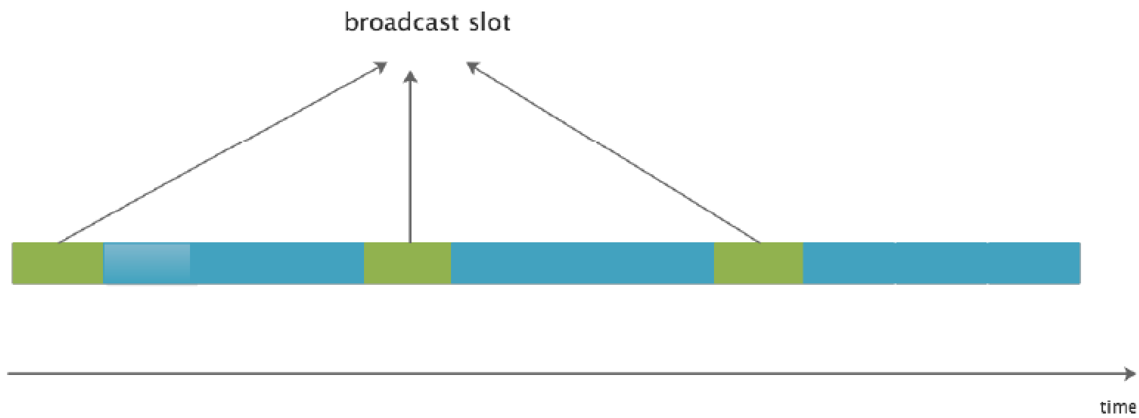

Figure 4

Accordingly, techniques are described herein to resolve this problem using Software Defined Networking (SDN). These techniques impact as few non-target nodes as possible during upgrading, and make use of as much unicast propagation as possible. Briefly, a genetic Simulated Annealing (SA) algorithm is used to determine an optimal packet distribution strategy that can reduce traffic cost as much as possible in a multi-vendor based WMN while upgrading firmware for a subset of the nodes.

As illustrated in Figure 5 below, the SDN controller may be provided between a Field Area Network (FAN) cloud center and Border Router (BR). The SDN controller may adopt the most optimal strategy for each kind of vendor nodes while upgrading their firmware. Customers may leverage Application Programming Interfaces (APIs) to upgrade a given type of node. The customers may send commands to the SDN controller, which generates related strategies as desired. The BR may obtain these policies from the SDN controller, generate packets, and propagate the packets to WMN nodes.

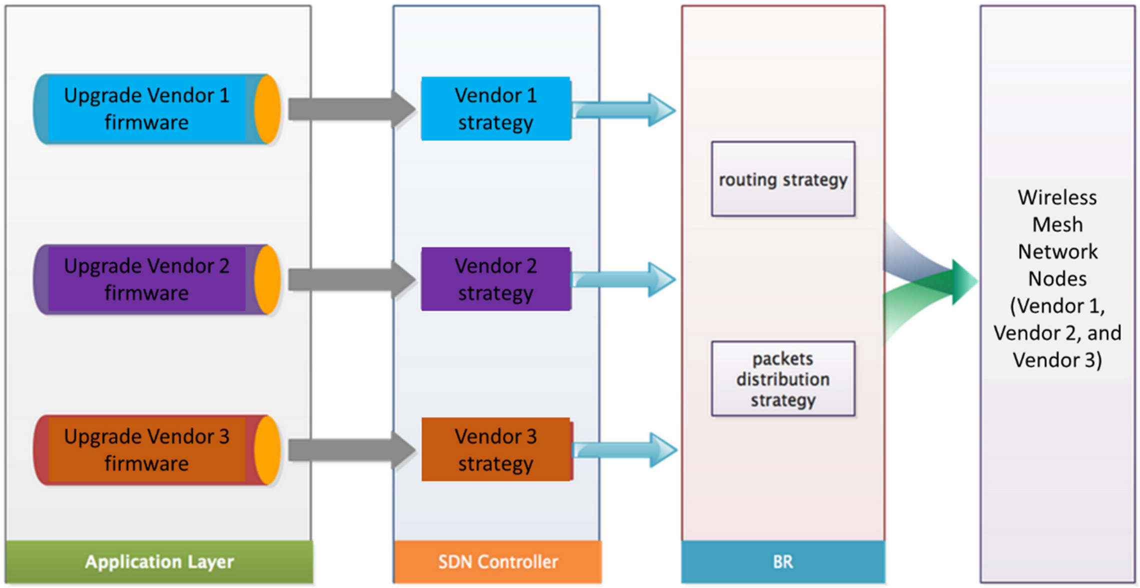

Figure 5

As illustrated in Figure 6 below, nodes may be used as broadcast agents that propagate FU frames using broadcast techniques after receiving the frames from unicast propagation. The SDN may push this policy to these agents. The red nodes may be planned for upgrading. Rather than using broadcast propagation in the whole WMN, an agent node may issue the following policy. First, if there is more than one target node gathered in an area, one node in the center is selected as an agent to send FU packets via a unicast link. All FU packets which are distributed to agents with limited broadcast times N may be pushed by the SDN controller (e.g., if N is 3, these packets may be spread in broadcast via 3 hops to ensure that every target node is covered in this area). If the target node is an orphan node (e.g., the red node in the right corner), the SDN may build a unicast link instead of treating it as an agent.

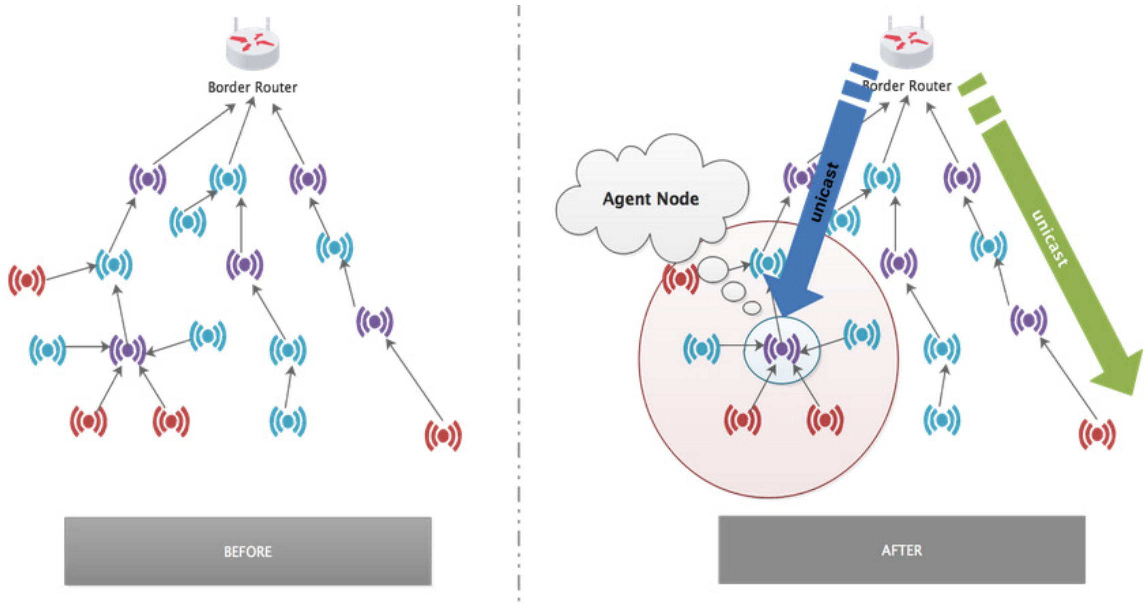

Figure 6

An SA algorithm may also be used for selecting these agent nodes and deciding how to distribute packets on the air. The SA algorithm may be leveraged to select the agents and calculate the correct number N of them. SA is a genetic algorithm, which comes from thermodynamics theory. Formula 1 below indicates the rule.

$$\mathrm{P(dE)} = e^{\frac{dE}{T}} \quad dE < 0$$

Formula 1

dE represents the difference between the current solution and one change. If dE is equal to or larger than 0, this change is acceptable. Otherwise, this change is acceptable with probability P(dE). T represents the temperature, which in this case is analogous to the number of iterations. E denotes a function to calculate a metric value for every change. In order to reduce the cost (for both traffic and undesired nodes), the final solution may have several goals. First, the final solution may have more agents. Each agent can cover several target nodes, and the more target nodes covered, the more traffic is saved. Second, the final solution may have more broadcast iterations (i.e., N is preferred to be as large as possible for each agent). The local broadcast link is more efficient than multiple unicast links. Third, the final solution may have fewer non-target nodes. In order to avoid undesired nodes spreading group traffic (e.g., FU packets), this quantity should be relatively low. Fourth, the final solution may have fewer orphan target nodes. Each orphan node requires an independent unicast link, which is not desired due to redundant traffic. As such, the number of instances of this kind of node should be minimized.

Accordingly, formula 2 illustrates a function to measure the effort/cost for each change.

$$E = \frac{m+\sum_{i=1}^{m} N(i)}{t+k+1}$$

Formula 2

In this example, there are m agents, t undesired nodes, and k orphan nodes. Because each agent has a broadcast iteration, they are placed into a set N = {N(1), N(2), ..., N(m)}. Crossover rate P_c, mutation rate P_m, temperature T_0, gradient of cooling k, the maximum number of iterations I are initialized. It is assumed that all changes are known (i.e., many solutions for how to place agents and orphans). These changes form a set Q(n) (n >= I). Thus, the SA algorithm is detailed as follows:

- Step 1: Initialize with solution Q(1), T <- T_0, and then delete Q(1) from Q.
- Step 2: Try solution Q(x) randomly and proceed to Step 3 unless the number of iterations is less than I.
- Step 3: Apply crossover and mutation with probability P_c and P_m according to the genetic algorithm. Obtain current fitness E' from formula 2. Set dE = E' - E. If dE > 0, accept this change, otherwise, accept it with the probability provided by Formula 1.
- Step 4: Delete Q(x) from Q, T <- T*k. Proceed to Step 2.

The best solution is obtained with this algorithm. The SDN controller may send a policy to selected agents. Once the agents receive the policy they can determine their new role. The agents may spread group management packets (e.g., FU packets) to their neighbors in broadcast channels with limited hops as required from the SDN.

As illustrated in Figure 7 below, because the topology often changes in Low-power and Lossy Networks (LLNs), the SDN controller may adjust its strategies according to latest topology periodically (e.g., every 30 minutes or 1 hour). When nodes change their positions in a WMN, they inform the BR with Destination Advertisement Object (DAO) frames. The BR collects all of this information and then generates a new topology for the

SDN controller. The controller updates the optimal strategies using the aforementioned algorithm and issues them to the BR, which then updates agents and orphans accordingly.

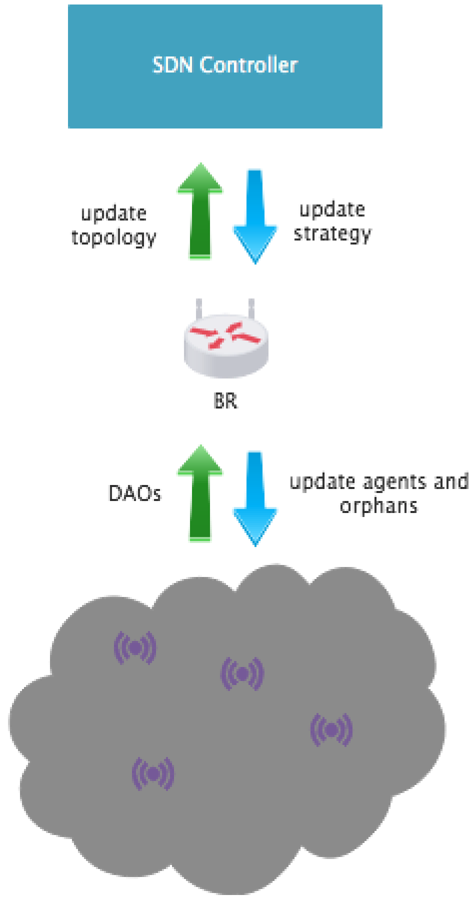

Figure 7

In summary, techniques are described herein to transform logical group traffic into a combination of broadcast and unicast messages rather than flood of broadcast messages. These techniques limit redundant traffic to manage logical group traffic over WMNs.