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SMART DEPLOYMENT WITH ROUTING PROTOCOL FOR LOW-POWER AND LOSSY NETWORKS TOPOLOGY IN WIRELESS MESH NETWORKS BY MULTI-OBJECTIVE OPTIMIZATION ALGORITHM

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ABSTRACT

Techniques are provided for a multi-objective model for the Wireless Mesh Networks (WMNs) planning problem where three conflicting objectives are optimized simultaneously. Different discrete recommendation areas may form different network topologies, thus screening out the best recommendation. In order to evaluate the network topology, a mechanism is described to simulate the radio coverage and Routing Protocol for Low-Power and Lossy Networks (RPL) simulator to search the optimal positon by new deployments generated iteratively. In particular, provided are (1) a networking deployment mathematical model based on RPL topology, (2) a multi-objective optimization approach to search the best RPL topology, and (3) model resolution after optimizing the candidate sets.

DETAILED DESCRIPTION

A mesh network may be a multi-hop network made up of millions of radio nodes organized in a mesh topology. A better deployment would improve network reliability, reduce costs, improve energy efficiency, and accomplish load balancing. In a large-scale deployed smart grid, an optimized and cost-effective deployment is highly dependent on many key factors such as network topology, radio interfaces per node, etc. Thus, proper network planning and analysis techniques are necessary to mitigate these issues in advance.

Routing Protocol for Low-Power and Lossy Networks (RPL) provides the mechanism to form the topology in a mesh. The Objective Function (OF) dictates how parents in the topology are selected, which may determine the traffic flow between the Connected Grid Endpoint (CGE) and the Connected Grid Router (CGR). Sometimes a range extender which acts as a fill-in to connect isolated node clusters may be added (and gateways (GWs) similarly). Depending on the actual situation, the deployment of CGE is determined by user distribution. The deployment of CGRs, GWs, and range extenders may help form the network topology. This means that developing a set of best design practices may enable successful network deployments that are optimized for performance and cost.

Figure 1 below illustrates a mesh network overview.

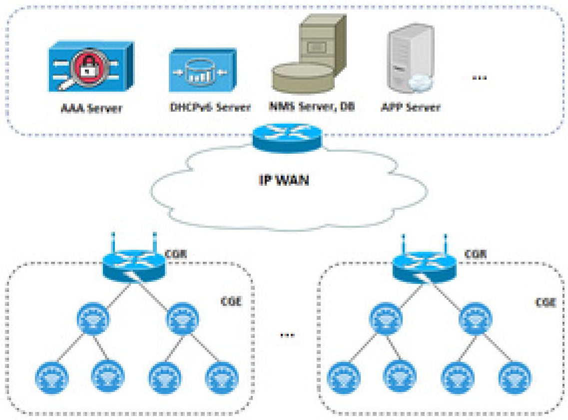

Figure 1

Figure 2 below illustrates typical Radio Frequency (RF) planning for CGR deployment.

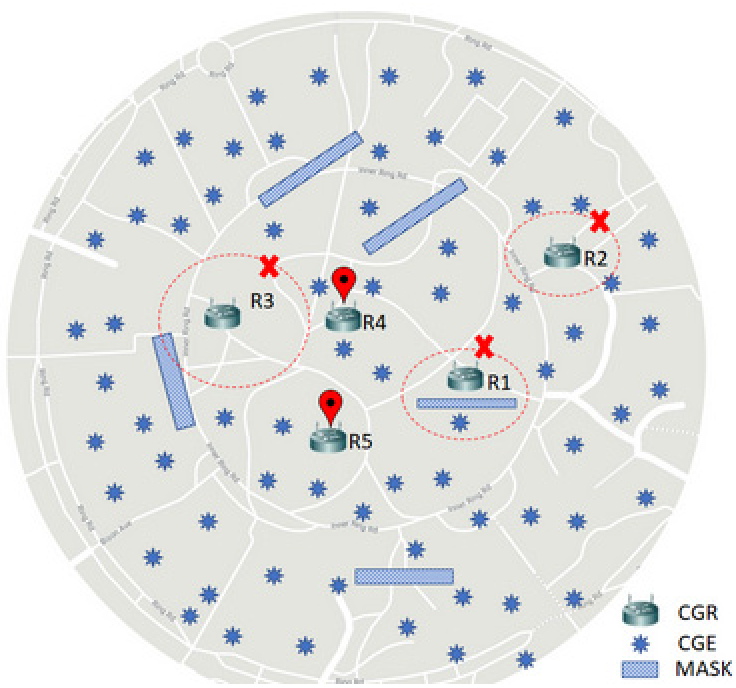

Figure 2

Several typical unreasonable deployments are shown.

In a first example case, router R1 is deployed close to buildings which leads to partial-directional signals being blocked by buildings. In a second example case, router R2 is far away from the center of deployments which makes the topology unbalanced. In a third example case, router R3 has so few neighbors that no nodes can join the topology. In a fourth example case, R4 and R5 are both in great deployment, but if high throughput is required to deploy two CGRs, R4 and R5 are not the best deployment.

To derive a useful deployment model, the following assumptions have been made. First, RF coverage is not a standard circle but an uneven pattern that depends on the environment. It requires complex physical parameters to build an accurate transmission model, which is difficult to implement. To simplify the analysis model and introduce the algorithm, it may be assumed that the RF coverage range is the disk region with radius r.

Second, due to the complexity and scale of Wireless Mesh Networks (WMNs), some with over one million nodes, it is essential to divide the deployment into different Personal Area Networks (PANs). Described herein is a planning algorithm for a divided sub-area. As to the deployment on the PAN divided method, another idea based on this mechanism will be introduced.

A networking deployment mathematical model based on RPL topology is provided.

Figure 3 below illustrates a flowchart for deployment optimization based on RPL topology.

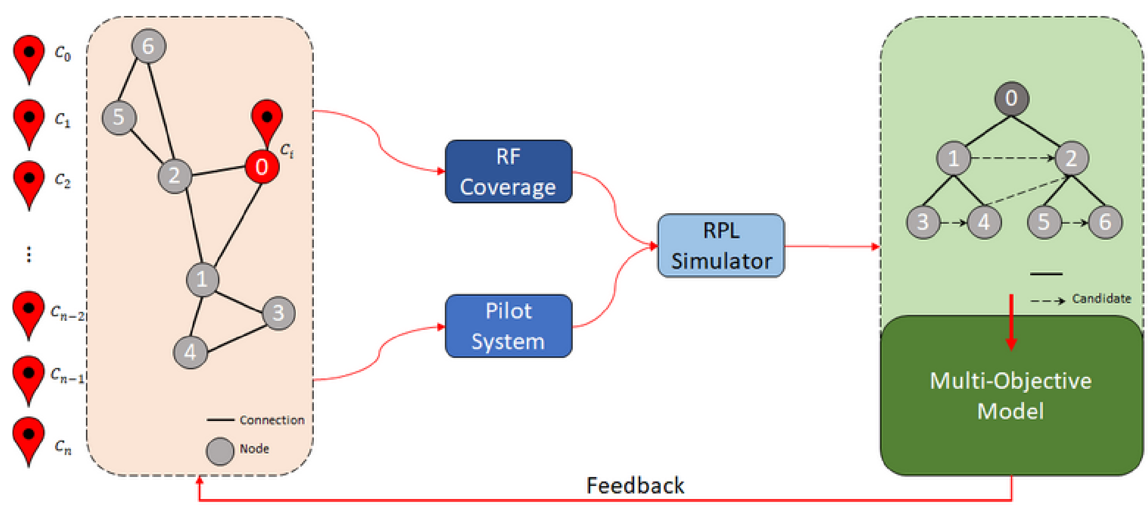

Figure 3

Internet Protocol version 6 (IPv6) RPL provides a traffic mechanism between devices inside the Low-Power and Lossy Network (LLN) and central control point. It organizes a topology as a Directed Acyclic Graph (DAG) that determines the upstream and downstream flow of data. Hence the evaluation criterion for the planning deployment should depend on the network topology. In order to generate corresponding topology with a given router deployment, a mechanism to simulate the radio coverage and RPL simulator is described.

The RF coverage model may approximate the signal strength (e.g., path loss, etc.) between each two nodes, which incorporates a three-dimensional model of the geographical area (e.g., buildings, trees, etc.). The solution of coverage mode may be the input of the RPL simulator which can simulate the networking formation process of RPL protocol to generate the DAG.

Because the real RF coverage is complex and dynamic, the prediction of this model may be biased but very close to the ideal deployment. Therefore, another mechanism is provided to improve the accuracy, referred to as a patrol system, which implements the data collection on site as the input of the RPL simulator to generate a more accurate topology. This may involve assigning a temporary CGR on the recommended position based on the ideal mode algorithm and then collecting all the node's information after joining the PAN or sending an Unmanned Aerial Vehicle (UAV) above the deployment area.

C1, C2, ..., Cn are potential candidate locations for routers, GWs, and range extenders. The optimal deployment may be found by generating new deployments iteratively.

A multi-objective optimization approach to search for the best RPL topology is provided.

Many discrete router recommendation areas may form different network topologies, and as such screening out the best recommendation is the core of this algorithm. A multi-objective model for the WMNs planning problem is provided where three conflicting objectives are optimized simultaneously: minimizing the average hop, maximizing the quality of the topology, and minimizing the number of routers, Distribution Automation (DA) GWs, and range extenders.

Minimize: $\sum_{i=0}^{m}\sum_{j}^{n} h_{ij}\omega_j$ (1)

Minimize: $\sum_{i=0}^{m}\sum_{j}^{n} q_{ij}\varphi_j$ (2)

Minimize: $\sum_{k\in S} r_k + d_k + e_k$ (3)

$\vdots$

Subject to: $\sum_{j=0}^{n} w_j = 1$ (4)

$\sum_{j=0}^{n} \varphi_j = 1$ (5)

$h_i \le H, i \in [1, m]$ (6)

$C_i < K, i \in [1, m]$ (7)

$\omega(G) = 1$ (8)

$r_k,\ d_k,\ e_k\ \in \{0, 1\},\ k\ \in S$ (9)

$\vdots$

n is the number of nodes in network and m is the maximize number of parents in protocol, S is the candidate deployment sets {1,2,...,h}, r_k is a router deployed at position k, corresponding d is the GW, and e is the range extender. The variable h_{ij} represents the hop of all parents. For example, h_{10} is the hop of node1's preferred parent, h_{11} is the hop of the first candidate, and h_{12} is node1's hop if it does not have a second candidate. The variable qij represents the normalized representation of a signal link quality to all parents where i is the node index and j is the parent index. The coefficient ω, φ represents the weight of each coefficient in the weighted sum. The constant H is the maximized hop, h_i is the hop of node, and G=(V, E) is the network topology graph.

The object function (1) may evaluate the degree of centralization and the average hop in the topology. Function (2) may maximize the quality of topology to evaluate the overall quality of the network topology. Function (3) may minimize the number of routers to reduce the total cost of the system. Constraints (4) and (5) are coefficient matrices of all parents, and the weight coefficient depends on the stability of the network. Constraint (5) implies the maximized hop in the topology. Constraint (6) indicates that there is a limit to the number of children, which may improve the balance of traffic. Constraint (7) implies that the branch of graph must be one which means all nods must be involved.

Figure 4 below illustrates one candidate in a multi-objective model.

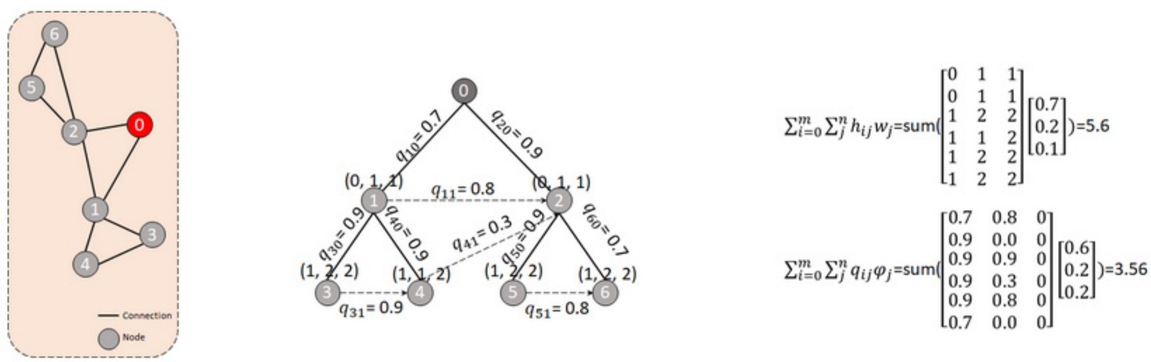

Figure 4

Model resolution may occur after optimizing the candidate sets.

The resolution of the model has three objective functions and several constraints, making it difficult to solve because it has multiple solutions as a set of solutions located in the front of Pareto. There are many algorithms to solve the multi-objective model, such as Particle Swarm Optimization (PSO), Non-dominated Sorting Genetic Algorithm (NSGA-II) for multi-objective optimization, etc. Usually the deployment zone may be divided into discrete sets, but the more candidate position sets, the more complicated to resolve the model. According to the distribution of deployment, candidates may sample from the signal overlap region.

Figure 5 below illustrates a candidate sample from a signal overlap region. The darker in region, the denser the sample.

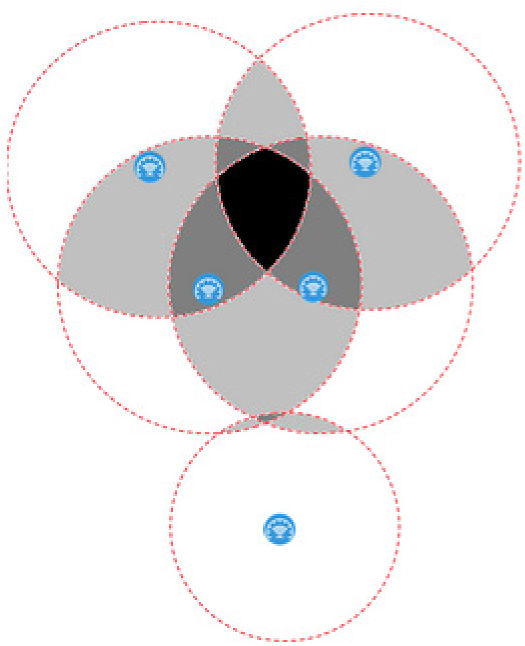

Figure 5

In summary, techniques are provided for a multi-objective model for the WMNs planning problem where three conflicting objectives are optimized simultaneously. Different discrete recommendation areas may form different network topologies, thus screening out the best recommendation. In order to evaluate the network topology, a mechanism is described to simulate the radio coverage and RPL simulator to search the optimal positon by new deployments generated iteratively. In particular, provided are (1) a networking deployment mathematical model based on RPL topology, (2) a multi-objective optimization approach to search the best RPL topology, and (3) model resolution after optimizing the candidate sets.