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HIGH EFFICIENCY SLEEP SCHEDULE FOR BATTERY BASED ENDPOINTS IN LOW-POWER AND LOSSY NETWORKS

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ABSTRACT

Techniques are described herein for a high efficiency sleep schedule method to save energy for Wireless Mesh Network (WMN). Nodes are not distinguished as Full Function Device (FFD) or Reduced Function Device (RFD), as the strategy depends on hop count and the parent node's sleep schedule. This is an improvement over current WMNs, which do not account for power management for Battery Based Endpoint (BBP) devices.

DETAILED DESCRIPTION

Mesh networks are widely used in smart-grid fields, which connect each node with a channel time slot. Currently, most endpoints contain an electricity meter, which is always connected with power line, and as such do not care about saving energy. However, power management is more important in water meter or gas meter marketing.

Most nodes of a mesh waste energy awaiting neighbor nodes' random connections, although they seldom send data to neighbors most of the time. Figure 1 below illustrates an example topology of mesh networking, which contains three hops.

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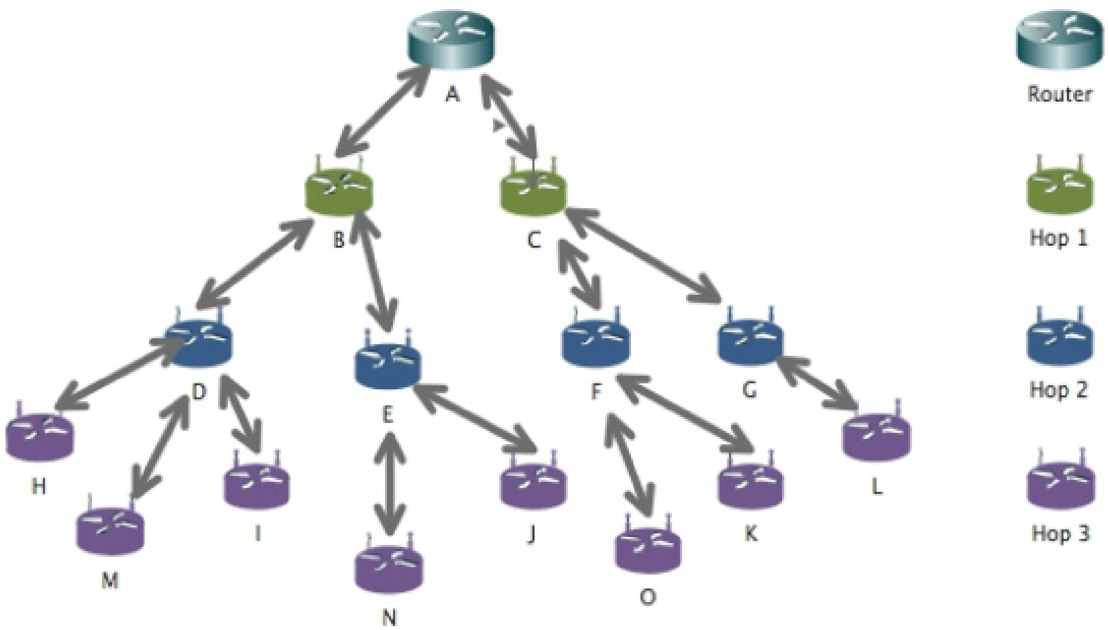

Figure 1

The purple nodes, which belong to Hop 3, are leaf nodes. They send their own data to their preferred parent. The dark blue nodes, which belong to Hop 2, are routing nodes. They not only send their own generated data, but also relay data of Hop 3 nodes to their parent nodes. The green nodes, which belong to Hop 1, are also routing nodes. They need to transmit both their own data and other data from Hop 2 and Hop 3.

Figure 2 below illustrates the statistics for the throughput of each node in the topology of Figure 1.

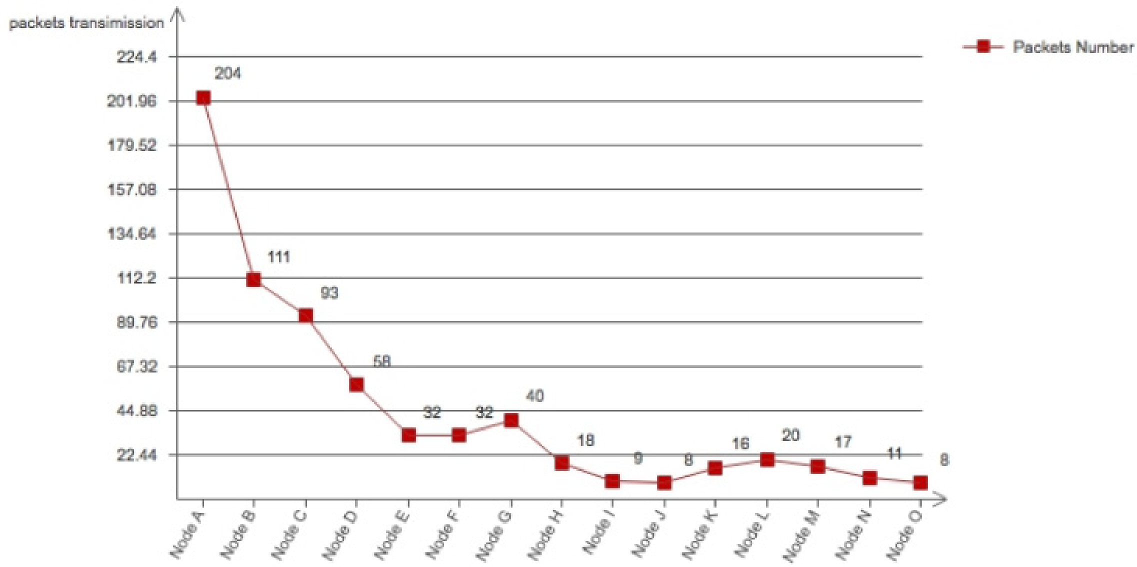

Figure 2

The more in depth nodes are, the less traffic they transmit. The nodes in the mesh, which have low throughput, could shut down the Radio Frequency (RF) chip and enter into deep sleep or standby mode until an event wakes them up. Thus, techniques are presented for a high efficiency sleep schedule for Battery Based Endpoint (BBP) in Low-power and Lossy Networks (LLN).

The Routing Protocol for LLN (RPL) depth is leveraged to arrange a suitable sleep schedule for each node. The deeper the node is, the longer it sleeps. Furthermore, a formula is defined to calculate how long a node could sleep for based on its depth. A random algorithm is also leveraged to make sure nodes could stagger their working time slots with the same depth. A ladder architecture for the sleep schedule ensures the lowest latency of the networks is achieved.

Normally, each node in a mesh has its own Unicast Schedule (US), which contains a Unicast Channel Sequence (UCS) and Unicast Dwell Interval (UDI). In addition, each one has a common Broadcast Schedule (BS), which contains a Broadcast Channel Sequence (BCS), Broadcast Interval (BI), and Broadcast Dwell Interval (BDI). Figure 3 below illustrates these details in one example.

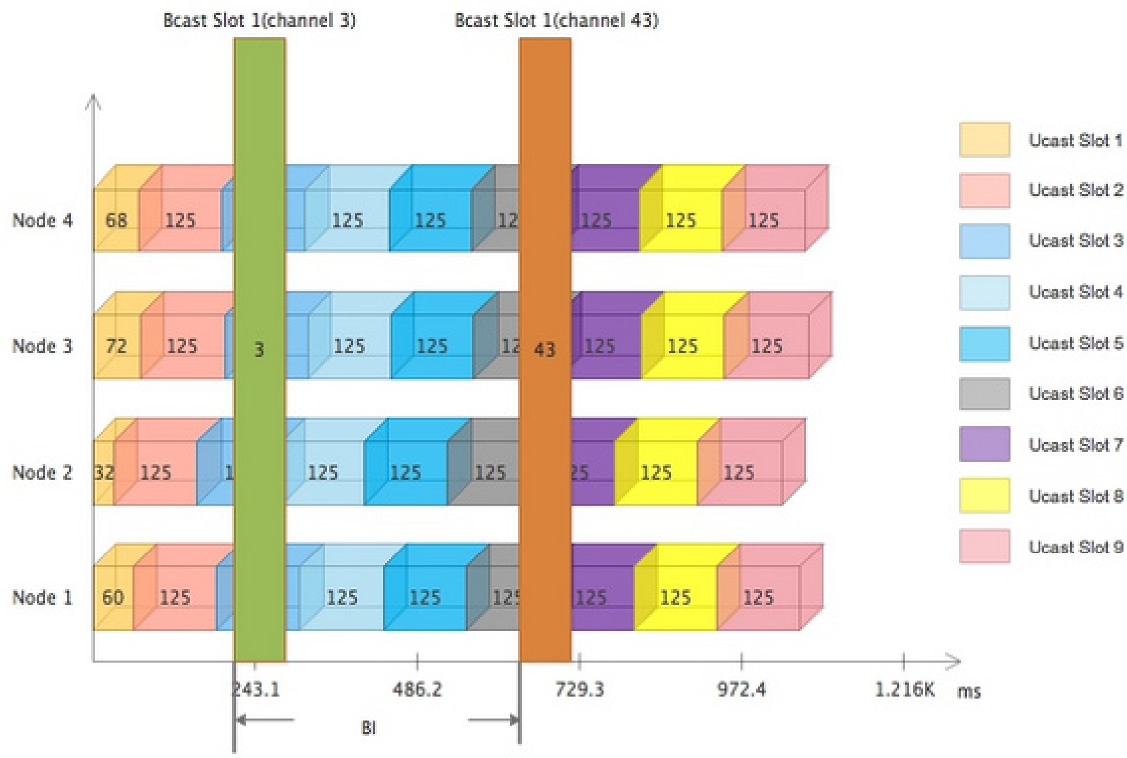

Figure 3

Because each node has a common BS configuration, in addition to the throughput statistics of each hop as shown in Figure 2, a method of high efficiency sleep schedule for BBP in mesh networking is provided.

The more packets the node has to transmit, the less time the node can use to sleep. A metric referred to as Expected Sleep Index (ESI) represents a measure of the duty-cycle of the sleep period in a Wireless Mesh Network (WMN). ESI may be calculated by the following formula:

$$\mathrm{ESI} = 1 - \frac{1}{2^x} \qquad x = \left\lfloor log_2^{(hop+1)} \right\rfloor$$

As illustrated in Table 1 below, the formula may be used to calculate the ESI accordingly by hops.

Hop Number	ESI	Examples of Figure 1
1, 2	50%	Node B, C(Hop 1) Node D, E, F, G(Hop 2)
3, 4, 5, 6	75%	Node H, I, J, K, L, M, N, O(Hop 3)
7, 8, 9, 10, 11, 12, 13, 14	87.5%	
15, ..., 31(enough large)	93.25%	

Table 1

One exception is if Node A is a Border Router, which is always awake, and never sleeps.

With reference to Figure 1, and according to the ESI formula, both Nodes B and C are Hop 1, and will therefore use 50% time to sleep. If one is awake and the other is sleeping, that will be helpful for avoiding a collision. An example sleep schedule is illustrated in Figure 4 below.

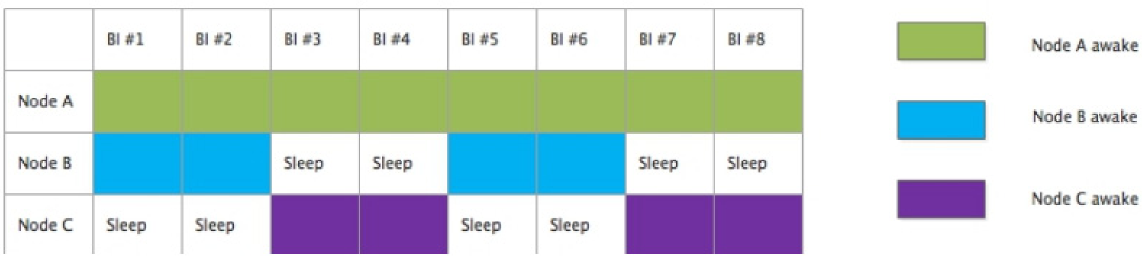

Figure 4

Channel time slots may be distributed equally for the same hop nodes, which uses the following formula.

$$y = \text{hash}(x), \quad x = \text{eui64} \qquad (1)$$

$$\text{slot} = \begin{cases} 4n, 4n+1 & if\ y\ is\ odd\ number \\ 4n+2, 4n+3 & if\ y\ is\ even\ number \end{cases} \qquad (2)$$

As illustrated in Figure 5 below, the hop 2 slot schedule in the Figure 1 topology may be similarly obtained.

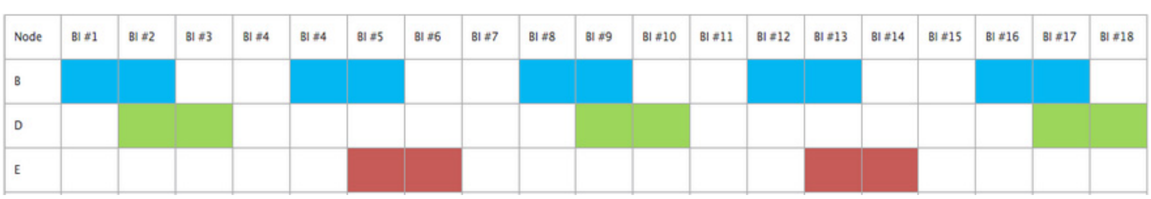

Figure 5

Each hop may use two BIs as the awake period. The first BI slot is used to communicate with the parent node, and the next BI slot is used to exchange data with the sub-node. Figure 6 below illustrates the whole process, which looks like a ladder and minimizes the latency.

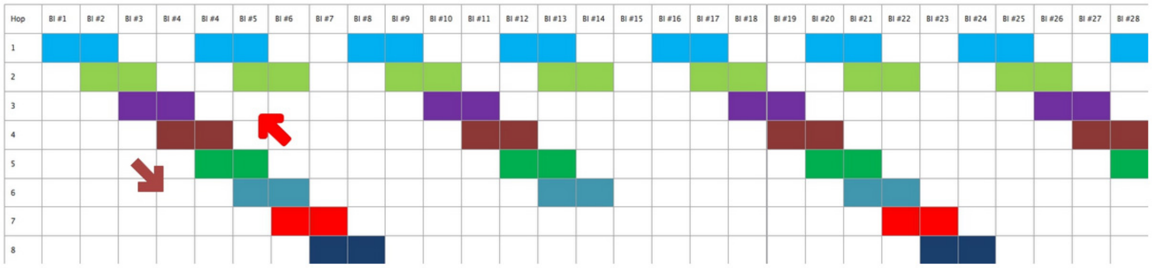

Figure 6

A small network as illustrated in Figure 1 was tested. Figure 7 below illustrates the obtained results. Four aspects were compared, including energy consumption, data transmission latency, collision probability (i.e., the total packets error probability of all nodes in the network), and stability (e.g., the Destination-Oriented Directed Acyclic Graph (DODAG) Information Object (DIO) version may be used to compare).

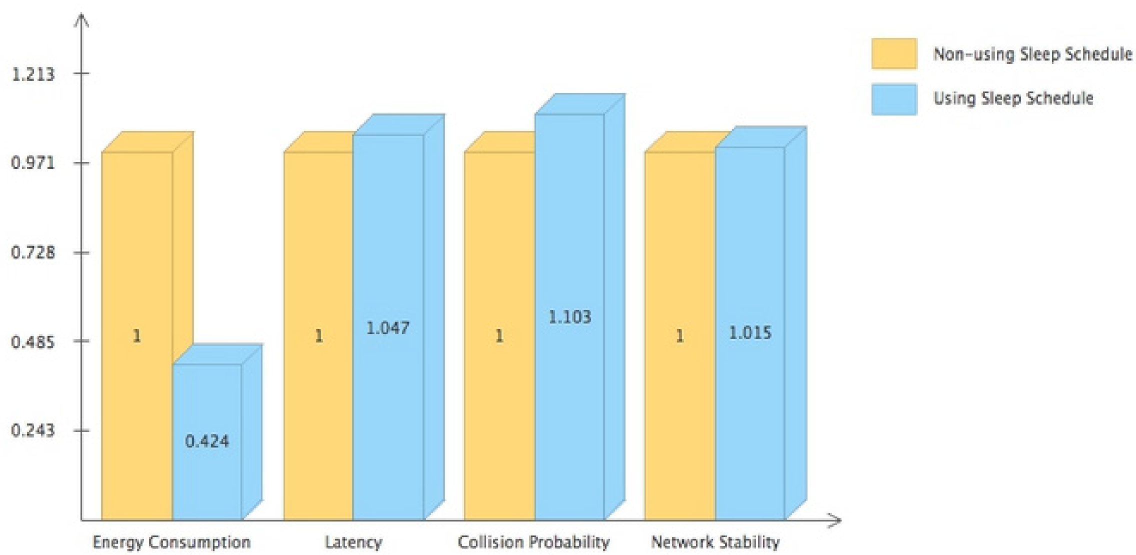

Figure 7

Considering normalization, all statuses of non-using sleep schedule strategy is set to 1.0 units. In these results, approximately 60% energy is saved without affecting other key performances of the network in the meantime.

In summary, techniques are described herein for a high efficiency sleep schedule method to save energy for WMN. Nodes are not distinguished as Full Function Device

(FFD) or Reduced Function Device (RFD), as the strategy depends on hop count and the parent node's sleep schedule. This is an improvement over current WMNs, which do not account for power management for BBP devices.