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Enhanced Design Consideration for Mobility Support in Internet of Things

Wan Fariza Wan Abdul Rahman[1]* and Aisha Hassan Abdalla Hashim[2]

[1]Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA Kelantan, Bukit Ilmu, Machang, Kelantan, Malaysia
[2]Kulliyyah of Engineering, International Islamic University of Malaysia, Jalan Gombak, 53100, Selangor.

*wfariza@uitm.edu.my

Abstract: Mobility assistance is necessary for many Internet of Things applications (IoT), including real-time patient monitoring and vehicle tracking systems. Sadly, the proposed standard Routing Protocol for Low-Power and Lossy Networks (RPL) only takes into account static wireless sensor networks (WSN). For RPL, solid mobility support is essential to ensuring ongoing device connectivity. Additionally, inadequate mobility support causes data loss, increased energy consumption, longer delays, and a decline in application performance. Numerous solutions have been put up to address the mobility challenges, but none of them take into account various mobility models about pertinent elements. This article offers a variety of mobility models for use in mobile IoT applications. Understanding the mechanisms of various mobility models enables more effective implementation of application-specific RPL mobility assistance. Mobility patterns, or the actual movement behaviour of moving objects, are closely related to mobility models. Velocity, obstructions, whether a movement is solo or group-based, and other elements affect how a movement behaves. This work proposes the improved design of mobility support for RPL while taking into account all the variables and various mobility models.

Keywords: Internet of Things (IoT), mobility model, RPL

1 Introduction

Internet of Things (IoT) extends the scope of the traditional application of Wireless Sensor Networks (WSN), leading to many interesting applications such as intelligent transportation, healthcare monitoring, surveillance cameras, asset tracking, and smart home appliances. Their use cases include wearable technology, robotics and UAVs (Unmanned Aerial Vehicles), as well as automobiles, buses, and trains outfitted with ever-more-advanced sensors. Even the current trend indicates that IoT applications that need gadgets to be integrated into moving objects will expand even further in the future. For instance, common patient vital signs like body temperature, blood pressure, peripheral capillary oxygen saturation (SpO2), and textual data can be tracked in real-time in healthcare monitoring. The development of mobility support is required for this kind of real-time monitoring. Although the sensor devices were previously thought to be static, IoT is built on the extension of WSN. As a result, mobility support is not included in the design of the current sensor-based protocols. To facilitate mobility in IoT applications, a routing protocol with new specifications needs to be created.

The rest of this paper is organized as follows: Section II represents a background on RPL. In Section III, several issues related to mobility in RPL will be addressed. The main components to implement mobility support in RPL will be discussed in Section IV. In Section V, the concept of a mobility model is highlighted along with a brief comparison of the analysed mobility models. Section VI presents the conclusion and suggested next steps.

2 RPL Background

RPL is a standardized IPv6 routing protocol originally proposed by Internet Engineering Task Force (IETF) working group for Low and Lossy Networks (LLNs). This type of network consists of nodes which are typically operated with constraints on processing power, power consumption and memory. The communication links of LLNs are characterized by low data rate, short communication range and low transmission power.

RPL [1] routes packets using a tree topology built on the Directed Acyclic Graph (DAG). A single point known as the DODAG root serves as the root of each Destination Oriented Direct Acyclic Graph (DODAG) that makes up the topology. In WSN, the root is also known as the sink. The root serves as an IPv6 border router and is in charge of tying LLN to the outside network. By sending the DODAG Information Object (DIO) message to other nodes, the root initiates the development of the DODAG by transmitting relevant information, such as the RPL Instance ID and Rank (as shown in Figure 1 below).

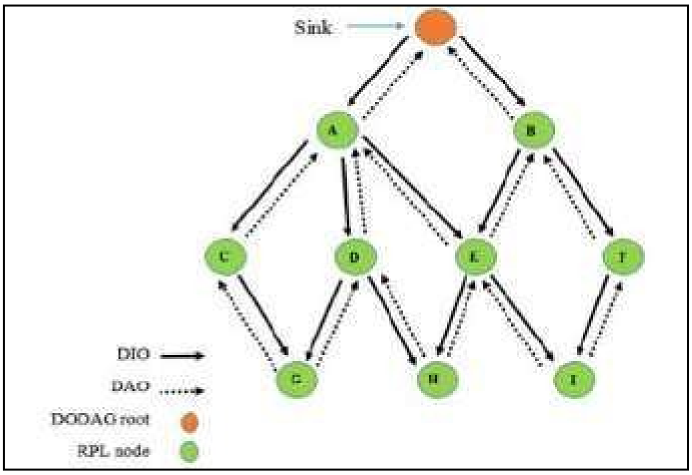

Figure 1: An RPL network and the exchange of DAO and DIO messages between the root and other nodes

A node chooses one of its preferred parents, which serves as the next hop to the root, after receiving many DIOs from several other nodes. Based on the Objective Function (OF) [2] to forward the packet to the root, the parent is chosen. The Trickle timer [3], is a controlled rate of DIO propagation over the network. When discrepancies are found, the timer accelerates the distribution of updated information; however, when the network is stable, it slows down. Nodes moving around generate considerable changes in network topology, which is one of the sources of the discrepancies. When there is no discrepancy found, the goal is to minimise control packet overhead. The DODAG Information Solicitation (DIS) message is another significant control communication in RPL. A node uses the multicast message DIS to start receiving DIO messages from its neighbouring nodes.

3 Mobility Issues in RPL

Network connectivity and the reliability of data transfer are negatively impacted by mobility. When a mobile node moves out of the range of its preferred parent, the node becomes unreachable and disconnected from the topology. In other words, the presence of mobile nodes might lead to less reliable links. As a result, more packet drops occur in the network. Further, for re-establishing the connections, high-control packet overhead would be imposed on the network. End-to-end delay would also increase as well as the transceiver activity imposed on the nodes, causing higher power consumption and lower node lifetime [4]. To provide continuous seamless connectivity for mobile nodes with constrained resources, an efficient mobility support protocol is crucial.

However, designing mobility support in RPL is challenging due to the limited resources (power, memory, and processing capability) of the devices. The current IPv6 mobility standard does not apply to this type of network since it could hasten the battery's quick depletion. This is a result of the control messages that are sent and received during each mobility event between the mobile node and the access router [5]. Thus, to reduce the signaling cost and power consumption, any mobility solution for RPL should consider the minimization of mobility-related signaling traffic as well as the switching between attachment points by the mobile node.

Fast mobility detection, a quick reaction against topology changes (once the mobility is detected) and attaching to new viable points to avoid disconnectivity are all the requirements for an efficient mobility support protocol [6].

4 Elements of Mobility Support

Hard or soft hand-offs can be used to support mobility. The hard hand-off happens when the mobile node's connection to its chosen parent is broken because the parent has not sent a DIO message within the predetermined time frame. In response to this, a new connection is established.

In contrast, soft hand-off requires the activation of the connection between the mobile node and its new preferred parent before the disconnection of the current link. The purpose is to avoid losing data packets. Soft hand-off protocols outperform hard hand-off protocols in reducing the handover delay [6]. However, this approach requires an overhearing mechanism to monitor the link and measure the Received Signal Strength Indicator (RSSI) between the mobile node and its parent [7].

The proposed design in this paper applies for soft hand-off mobility support with five main elements: mobility detection, neighbour discovery, movement prediction and selection of new point of attachment (preferred parent selection) and updating the new path.

A Mobility Detection

Mobility detection can be accomplished by: (1) announcement by the mobile node using Reverse Trickle, (2) establishing/anticipated mobility based on node history, and (3) monitored disconnection [7]. The mobility support design presented here considers the last approach.

Reverse Trickle [8] is used by the preferred parents of mobile nodes to trigger DIO messages. The timer for sending DIO starts at the maximum value and halves the sending intervals after every new DIO transmission. On the other hand, monitored disconnection can be obtained by analysing the jitter between two DIO messages provided by the mobile node or the parent analysing RSSI to detect movement outside of range. RSSI is a measurement of the power present in a received signal.

When a mobile node is present in a specific coverage area, it is connected to a static preferred parent. The movement of the mobile node is detected by the preferred parent by probing the link quality. The data packets received from the mobile node are used by the preferred parent to periodically compute an average RSSI value. When the degradation of RSSI value is detected, the preferred parent assumes that the mobile node is about to leave its coverage area. As a notification, a unicast DIS message (flag = 1) will be sent to the mobile node. The current preferred parent continuously checks the RSSI values until the mobile node sends a request for disconnection, or the link quality deteriorates (RSSI reaches a predefined value of threshold). Once the threshold is reached, the preferred parent informs the mobile node to stop sending data [9].

B Neighbour Discovery

Upon receiving notification in the form of a DIS message (flag = 1) from a current preferred parent, the mobile node computes and estimates its position based on RSSI values. At the same time, the mobile node starts collecting information (including the RSSI values of the neighbouring nodes) for a new associated node. For this purpose, the DIS message (flag = 2) will be broadcasted to neighbouring nodes. Response from each neighbouring node will be obtained in the form of a unicast DIO message (flag = 1).

The mobile node computes the RSSI value of each link with each neighbouring node. The RSSI measures the separation between two nodes, with the signal's intensity inversely proportional to the separation [10].

C Movement Prediction

The mobile node can apply various mobility models accordingly for the estimation of its current position and direction to select the new preferred parent, which is the nearest static node to its future location and predicted to maintain the longest connection. This is to reduce the signaling cost as the attachment changes [11], [9]. A brief description of mobility models will be presented in the next section.

D Selection of New Point of Attachment/Preferred Parent Selection

If nearby mobile nodes are taken into account while choosing a parent, the parent with the lowest speed values will be chosen as the preferable one (on the supposition that the nodes' velocities are constant throughout time). By delivering the packet through the fewest mobile nodes and minimising switching between several points of attachment, the goal is to make the routes as stable as feasible. For each node to be aware of the velocities of all its neighbours, velocity values can be added to the option field in DIO messages and broadcast throughout the network. The asking mobile node ranks its neighbours by raising the order of their speed values after receiving DIOs [8].

Some nodes may have fewer energy sources and less burden than other nodes. Thus, when selecting a new preferred parent, the remaining energy of the node also need to be considered to avoid energy exhaustion of the sensor node operating with a battery. Subtracting energy loss from the total energy yields the leftover energy, also known as residual energy. The energy depleted at a node refers to the energy consumed while a node is in the idle, active, transmit and receive modes. Another element that needs to be considered is the queue size. The packets are dropped by the node when its queue is full [10].

Once the potential preferred parent has been selected as its forwarding node, the mobile node sends a child request packet (CRP) informing the requirements to satisfy its quality of service. The potential preferred parent checks its current capability in terms of energy expenditure and queue load before accepting the request. The acceptance or rejection depends on whether the requested requirements could be fulfilled by the potential parent or not. The parent node then informs the requesting mobile node about its decision by sending the parent reply packet (PRP) [12].

E Updating the New Path

The mobile node modifies its parameters, including rank, preferred parent, and default route, after choosing the new preferred parent [9]. To establish the new connection and update the routing table, the DAO message is sent [13]. A DAO No-Path message informing the previous preferred parent of the disconnection is delivered once the new connection has been made. Figure 2 below shows the flowchart for RPL's enhanced mobility support.

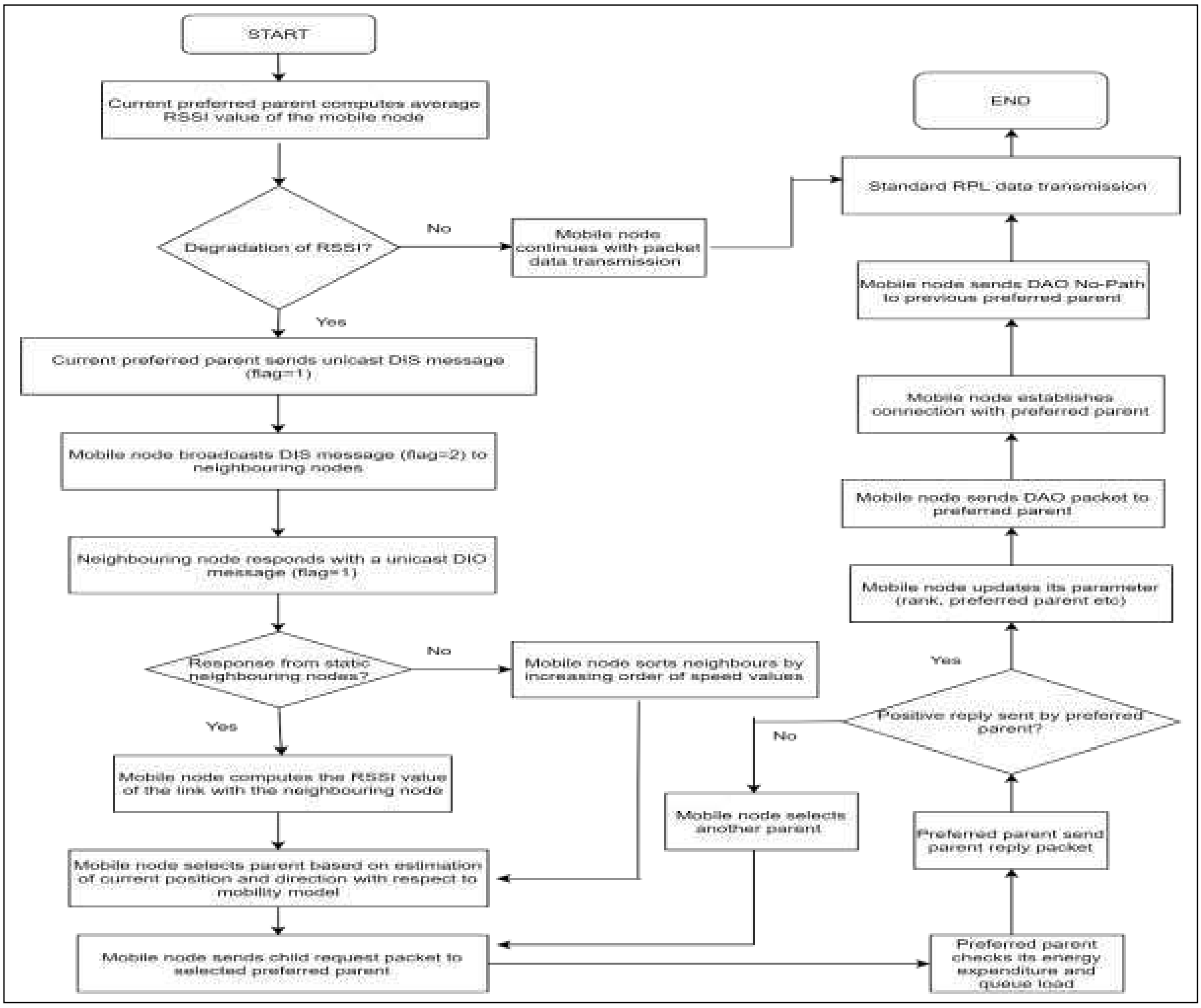

Figure 2: Enhanced mobility support in RPL

5 Mobility Models

Mobility pattern is the term used to describe the actual movement behaviour of moving objects. It can be determined by several variables, such as velocity, obstacles, impediments, acceleration over time, the distance between stopping points, location change, and whether the movements are individual or group-based [4]. To replicate the movement of IoT devices and objects in the corresponding real mobile applications, mobility models are created using mathematical representations. The routing protocols would behave differently under various mobility models.

The root/sink is believed to be stationary in many IoT applications [14]. There is a possibility for both trace-based and synthetic mobility models with static sinks. By gathering a wealth of information from real-world applications, such as the way the item moves, the locations it visits, its speed, and its acceleration, trace-based models can determine the movement behaviour of the nodes. The process of gathering data needs a sizable number of users using the right location-based technology, such as smartphones and smart tracking bands [4]. High-accuracy node movement predictions can be made with sufficient data, but the data collection method takes time. This limits the application of trace-based models to a narrow area [15].

Contrarily, a synthetic model is less accurate than a trace-based model. However, because of its adaptability, this approach is preferred. Using mathematical functions along with the mechanics of motion to imitate movement behaviour, it may be easily tailored to fit many scenarios and applications [4].

The mobility models can also be classified as accidental or intentional models. Accidental mobility models refer to a free movement of a human/object without limitation. In contrast, intentional models refer to the movement of a human/object restricted by certain factors such as movements of other objects and geographical constraints. Three variations of intentional mobility models: (1) mobility with temporal dependency, (2) mobility with spatial dependency, and (3) mobility with geographical restrictions. Mobility with temporal dependency refers to any movement whereby its attributes (such as angle of movement and speed of motion) are determined by the previous values. In spatial dependency mobility, a probabilistic equation determines the location of an object directly based on its current status. Mobility with geographical restrictions refers to the movement of objects confined by maps, borders and obstacles [4], [16]. Table 1 below summarizes the characteristics of various mobility models and their suitability for common IoT applications [4].

Table 1: Mobility models, their category, characteristics and suitability for common IoT applications

Mobility Models	Category and Characteristics	Suitable Applications
Gauss-Markov Mobility Model (GMM) [17]	• Mobility with temporal dependency • Prediction of the mobile's future location based on information gathered from the mobile's last report of location and velocity • After a predetermined amount of time has passed, the values for speed and direction are updated regularly.	Condition monitoring over a large area using computer-guided drones flying like swarms of flies
Manhattan Mobility Model (MMM) [18]	• Mobility with geographical restrictions • Only three possible chances of directional movement • Combination of probability value with randomness in determining the movement of nodes at every intersection point of the Manhattan Grid	Mobile node activity in city streets.
Reference Point Group Mobility Model (RPGM) [19]	• Mobility with spatial dependency • Group mobility models • Each node inside a group uses a reference point for its movement to define the current position	The behaviour of a troop on a battlefield, for example, or the movements of a collection of nodes in a terrain
Nomadic Community Mobility Model (NCM) [20]	• Group mobility model with spatial dependency • The path taken by a set of nodes when they move collectively from one location to another • Random movement	Military application Agriculture robotics
Pursue Mobility Model (PMM) [20]	• Mobility with spatial dependency • The pursuit of a target node by many nodes.	People or equipment tracking

Table 1: Mobility models, their category, characteristics and suitability for common IoT applications (continued)

Mobility Models	Category and Characteristics	Suitable Applications
Column Mobility Model (CMM) [20]	• Mobility with spatial dependency • Represent the moving pattern of a row of robots moving in a certain direction	Searching activity
Self-similar Least Action Walk Model (SLAW) [21]	• Synthetic walk traces of human movement • Entity mobility models	Control of mobile devices related to human users
Truncated Levy Walk Mobility Model (TLW) [22]	• Accidental mobility models • The Levy walk nature (commonly observed in animals) of human walk mobility • Consider geographical constraints including walk boundaries, physical obstructions and traffic	Human walk
Smooth Mobility Model [23]	• Mobility with temporal dependency • Based on several known features of human movement • Creates communities (denoted by clusters) with different levels of popularity	Human movement
Small World in Motion Mobility Model (SWIM) [24]	• Human movement patterns through their daily activities • Based on a simple intuition of human mobility: People go more often to places not very far from their homes and where they can meet a lot of other people	Support movable objects like cell phones, automobiles, and electronics
Tactical Indoor Mobility Model (TIMM) [25]	• Mobility with geographical restrictions and obstacles in particular walls using a graph-based approach	Military units in indoor urban warfare situations: - building security - bomb disposal operations
Random Street Mobility Model (RSM) [26]	• Mobility with geographical restrictions • The integration of location-based services to get accurate and realistic maps	Vehicular traffic in urban environments
Map-based SLAW Mobility Model (MSLAW) [27]	• Mobility with geographical restrictions • Introduction of geographic restrictions to SLAW in the form of maps	Control of mobile devices related to human users
Disaster Area Mobility Model (DAM) [28]	• Mobility with temporal dependency and geographical restrictions	Scenarios involving disasters like earthquakes, flash floods, and powerful tropical storms

6 Conclusion

This article highlights the issues of mobility in IoT. The enhanced design for mobility support in RPL, which is the standard routing protocol developed by IETF for IoT, has been proposed. Focus has been given to speed and energy consideration of the preferred parent chosen to reduce signaling cost while changing the attachment point in mobility event. Various mobility models applicable to IoT applications are also presented in brief. It is hoped that the idea presented in this article would pave the way for further research in designing and implementing better application-specific mobility support for IoT in the future.

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