Network Assisted Mobility Support for 6LoWPAN

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***Abstract*- This paper presents a network-assisted mobility support scheme for 6LoWPAN nodes, which enables multi-hop communication between the Gateway (GW) and the Mobile 6LoWPAN devices (MNs), with minimum mobility related signaling at the MN's end as compared to conventional mobility related protocols like MIPv6. The scheme provides mobility support to the MNs with the help of low cost static 6LoWPAN devices (SNs) which can be deployed in large numbers. In order to reduce the handover latency, the MN in the proposed scheme is assigned a fixed address which remains unchanged during its course of movement within the network. Moreover the scheme aims to reduce packets loss of the MN by predicting its future location and having a provision of buffering its packet at SNs when needed. The signaling overhead consumption needed to support a MN is determined through analytical modeling.**

Index Terms: 6LoWPAN mobility support, Network assisted mobility

I INTRODUCTION

IEEE standard 802.15.4 [1] has emerged as a strong technology for WSNs to morph Personal Area Networks (PANs) into Low power Personal Area Networks (LoWPANs). LoWPANs are characterized by low data rates, low power consumption, low cost, autonomous operations and flexible topologies. In order to fully realize a pervasive or ubiquitous environment, LoWPANs must be connected to the Internet Protocol (IP)-based networks [2].

As the technology is maturing with time, many intriguing applications are surfacing that require a certain degree of mobility among the PAN devices. However providing IP connectivity to mobile 6LoWPAN devices means that the devices needs to empowered with traditional mobility related IP protocols like MIPv6, HMIPv6 [3] etc. However, it is not feasible for the MN to be associated with host based mobility protocols as they require most of the signaling on MN's end.

This paper proposes a network assisted mobility support scheme which enables multihop communication between the GW and the MN, thus addressing the shortcomings of other network based mobility protocols like PMIPv6. Furthermore, since the MN is given a fixed link layer address from an address pool which does remains fixed the handover latency and thus packet loss is reduced. Also in order to minimize the packet loss of MNs, the scheme incorporates buffering and uses prediction of MN's future location. Additionally mobility is handled at adaptation layer in order to reduce the bandwidth consumed to transmit mobility related packets like Location Update to GW in multihop communication. The signaling overhead for the SNs is determined through analytical modeling. The overhead is determined with respect to parameters like speed and time.

The remainder of the paper is organized as follows. Section II, describes the related work followed by the 6LowPAN mobility requirements in section III. Section IV defines the system model and assumptions. The next section, section V describes the proposed scheme. Section VI discusses the communication scenarios followed by the network model in section VII. Performance evaluation follows next in section VIII and finally section IX concludes the paper.

II RELATED WORK

In [9], authors have proposed a design of micro mobility support for a sensor node roaming across several Access Points (AP) of a Bluetooth sensor networks. In it authors proposed to assign IP address to an AP and a sensor node to identify a MN instead of identifying it with channel number. Also they designed a middleware to carry IP packets over Bluetooth. However they assume that the sensor node is capable to perform single hop communication even if the MN is not that close to the AP. Moreover the MNs are expected to incorporate a middleware layer changes in their stack in order to support their mobility.

The host based mobility protocols like MIPv6, FMIPv6 and HMIPv6 was proposed by Internet Engineering Task Force. In MIPv6, when a node moves from one network to the other, the node itself updates its current care of address to its Home Agent. Also it performs Return Routability Test as security measures. HMIPv6 adds another level on MIPv6 and separates global mobility from local mobility. It introduces a new entity called mobile anchor point (MAP) which acts as a local home agent of the MNs [3]. FMIPv6 is another enhancement of MIPv6, which aims to reduce handoff delays for mobile connections. However, the host based mobility protocol involves most of the signaling on the MN's end which cannot be realistic for 6loWPAN nodes. Also the protocols expect the MN is expected to indulge into IP layer signaling including all signaling required to configure an IP address on a new link. Beside this, these protocols require Duplicate Address Detection (DAD) operation needed to be performed by anchor points which contributes towards a handover latency of minimum of 1 second [3]. Moreover, these protocols demands a complex host stack, which is not feasible for 6LoWPAN considering their inherent constraints. Proposed work achieves better performance as compared to the abovementioned protocols in ways. Firstly static addressing reduces handover latency by excluding DAD operation. Secondly using 6LoWPAN short address instead of long IPv6 address the proposed scheme reduces the signaling bandwidth. Another important consideration that we have in our scheme is to allow anchor points (SN in this case) to utilize sleeping mode to conserve energy, which is not supported by HMIPv6. It assumes that MAP is always available.

Network based localized mobility like PMIPv6 [8], also proposed by IETF, is where the network side (Mobile Access

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Gateway, MAG) performs the mobility-related signaling on behalf of the MN. The interface between the MN and MAG is defined at the IP layer and is applied to single hop [7]. However single hop communication is not suitable for 6LoWPAN devices keeping in mind that the MNs are energy constrained. This is due to the fact that as the MN moves farther from the GW, it has to increase its transmission power to communicate with the GW.

III MOBILITY REQUIREMENTS IN 6LOWPAN

Mobility requirements in 6LoWPAN include [7]:

1. Providing fast handover detection.
2. The MNs should be addressable by any correspondent irrespective of its whereabouts.
3. Also the signaling is also required to be minimized considering the resource constraint characteristic of the LoWPAN devices.

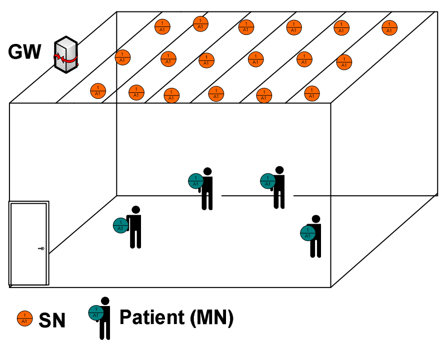

Figure 1: Mobility scenario in 6LoWPAN

Figure 1 depicts a hospital building which may have several rooms. If a patient is suffering from a heart problem such that his heart rate has to be constantly monitored he has to be confined to one place. Alternatively, a sensor can be attached to the patient while he moves within the hospital premises. In every room SNs are deployed which help the MN to communicate with the GW. The sensor device can constantly transmit the readings to the doctor or the concerned person by associating with one of the SNs.

IV SYSTEM MODEL AND ASSUMPTIONS

Our proposed mobility scheme is based on the following network assumptions:

1. A MN is an active device.
2. SNs are arranged in a grid where two neighboring SNs in the same row have a distance of $\frac{\sqrt{3}}{2}R = 0.86R$ between them and two neighboring SNs in the same column have a distance of R between them; where R is the transmission range of a SN.
3. When all SNs in a column are in active sate, the SNs in neighboring columns are in sleep state. The distance between the neighboring columns is taken to be $0.86xR$ so that there is no gap in the coverage area of the SNs when some of the SNs are in sleep state.
4. Each SN is aware of its row and column number with respect to the GW.
5. The current velocity of a MN depends strongly on its previous velocity. Thus fluid flow mobility model can be used to model the mobility pattern of the MN.
6. The nodes in the first row of the grid, which are closer to the GW, are comparatively more powerful nodes. They have larger transmission range than the other SNs in the network to communicate with the GW.
7. The GW has location information of all the SNs in the network.
8. IEEE 802.15.4 networks provide two types of addresses, IEEE EUI64-bit extended address and 16-bit short addresses.
9. The SNs are assigned with IPv6 address and with 16 bit short address.
10. The IP address of the MN and 16-bit short address or MN ID remains the same irrespective of its location in the network.
11. Each 6lowPAN device has the same transmission signal strength and receiver sensitivity.
12. The interoperability between IPv6 network and the IEEE802.15.4 device is handled by the adaption layer [16]. Every adaptation layer packet begins with a 8 bit dispatch value that identifies the type of header following it.
13. Each sensor node is equipped with an antenna array in order to obtain Angel of Arrival (AoA) measurements.

V PROPOSED MOBILITY SUPPORT SCHEME

Any proposed mobility support scheme should be lightweight as the 6LoWPAN nodes are extremely resource constrained.

In order to provide mobility support to 6LoWPAN nodes this paper introduces another layer of hierarchy between the MNs and the GW. This can be seen in figure 2. This level of hierarchy contains some static 6LoWPAN nodes which have the same characteristics and constraints as the MNs. The SNs are low priced devices which can be deployed in large quantity in a region where mobility support of the MNs is required. These enable multi-hop communication between the GW and the MN as seen from figure 2.

In figure 2, GW provides the MN the IP connectivity. Other than performing the normal chores for 6LoWPANs networks like protocol translation and address translation, the GW is assigned some extra functionality in the proposed scheme to support mobility. These include storing bindings which maps the MN's ID, its current location, Home address, and CN's IP address. Thus it can be seen that the proposed scheme also provides location aware data from the MN, which can be more useful in some applications. Beside this the GW also sends Binding Updates (BUs) to MN's Home Agent (HA) and Correspondent Nodes (CNs).

Primary SN (PSN) in figure 2 acts as anchor points for the MNs. They send Location Update (LU) to the GW on MN's behalf when the MN associates with them in order to communicate with the GW. Moreover, the PSN helps in routing the data packets of the MN to the GW.

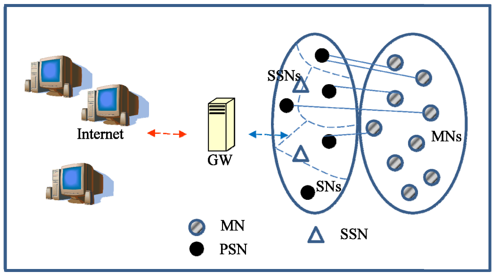

Figure 2: Mobility Support Scheme

Thus the MN does not have to perform route discovery every time it needs to communicate with another node. The PSN can be deployed optimally as shown in figure 2. During initialization, every PSN identifies its relative location information with respect to the GW using existing localization algorithm [5, 10, 11]. Based on the location information it can easily identify its row and column number in the grid. Since the distance between two neighboring nodes is *R*, the PSN can calculate its row and column number accurately by taking in account the localization error in meters. The PSN then exchange its location information (row and column number) with its one hop neighbors. If the column number of two nodes is same then they become Paired Nodes (PNs). PNs become active or go to sleep state at the same time. This can be seen in figure 3. In this figure, PSNs 1 and 2 are PNs and therefore when they are in active state, nodes 5 and 6 are in sleep state and vice versa.

In order to make the network fault-tolerant Secondary SNs (SSN) can be deployed, which remains active all the time to monitor other PSNs in the network such that when one of them fails it behaves as a PSN.

A. MN entering the Network

In active state, a PSN periodically transmits a *hello_packet*, which contains PSN's short address. When a MN enters the network for the first time it scans the entire frequency channels to receive a *hello_packets* from PSNs.
Once it receives a *hello_packet*, it sends a *join_request* packet to the PSN from which it received the *hello_packet* of highest signal strength. The *join_request* message contains MN's Home address. The PSN then forwards the *join_request* packet to the GW. Upon receiving the *join_request* message, the GW assigns a unique ID (16 bits) and a care of address (IP). It then sends the MN's ID and its CN's mappings to the PSN in form of a *join_confirm* message. The PSN then informs MN of its newly assigned ID. The GW then sends a BU to the HA of the MN.

B. Handoff Support

This scheme proposes to predict the future location of the MNs in order to prevent packet loss. Additionally to limit packet loss, the PSN in the proposed scheme buffer MN's packet for a fixed amount of time *t*.
Figure 3 shows a MN with a possible initial position O. The MN can then move in different directions such as OB, OC and OA. The PSN with which the MN is currently associated determines the current location of the MN, using the Received signal strength and AoA (Angle of Arrival) of the received packets. AoA is defined as the angle between the propagation directions of an incident wave with respect to Y axis. Once the PSN computes MN's subsequent locations, it determines the direction in which the MN is moving. The direction can be specified with respect to X axis and can be given by Θ.

Case 1: $45 \leq \Theta \leq 90$ (degrees)
In this case when PSN determines that the MN is moving towards its active neighbor (node 2 in figure 3), it sends *new_node* message to the MN's future PSN. The *new_node* message contains MN' ID and the short address of the current PSN. The MN on the other hand, sends an *association_request* message to the new PSN as soon as it receives a *hello_packet* from it.

Case 2: $0 \leq \Theta \leq 45$ (degrees)
The PSN can assume that the MN is moving towards the next set of active nodes (Node 3 or 4 in figure 3). In this case when the RSSI value of the received packets has degraded beyond a certain threshold, the current SN sends a Premature LU (PLU) to the GW. The PLU contains the MN's ID, the current PSN's short address and angle Θ.

Upon receiving the PLU, the GW predicts that the MN is moving towards next column of active PSNs and thus determines the short address of the MN's future PSN based on the short address of the current PSN and angle Θ. When deciding this, it takes into consideration of the sleep-active transition of PSNs. It then tunnels the packets to MN's predicted future location. In order to prevent packet loss, the new PSN then buffers the packet for the MN. When the MN enters the communication range of the new PSN, it associates with it by sending an *association_request* message in response to the *hello_packet* from the PSN. The *association_request* message contains the MN's ID. The PSN then delivers all the MN's buffered packets to it and sends an LU message to the GW. In case the new PSN does not receive an *association_request* within a time interval *t* it returns all the packets back to the GW in form of *node_notfound* message. In this case when the MN associates with another PSN, the PSN checks whether it has received any *new_node* message from its active neighbors. In case if it hasn't then it sends a LU message to the GW. The GW then delivers all the buffered packets to the MN.

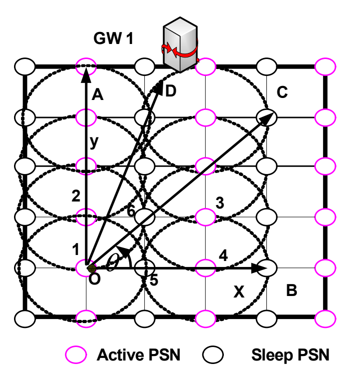

Figure 3: PSNs arranged in a grid

In a situation when the MN's current PSN goes to sleep state and the other set of sleeping PSN switches to active state, the MN associates with one of the newly active PSN. The newly active PSN then sends a LU to the GW.

VI COMMUNICATION SCENARIOS

When the MN has to send data packet to another MN it transmits the packet with a specific dispatch value. The dispatch value indicates that it is a data packet from a MN whose recipient is the GW. When the current PSN receives the packet, it forwards to its neighbor, which is close to the GW.

When the data packet reaches the GW, the GW determines the active column where the MN can be located. It then tunnels the packet to its nearest PSN in the active column. The PSN then extracts the packet and checks whether the destination MN is associated with or not. If it is then it delivers the packet to it, otherwise it forwards it to the next active neighbor in the column. This process continues until the packet reaches its destination. In case if a PSN determines that the MN is not in the active column anymore, it returns the packet to the GW, in form of a *node_left* message. In case if the GW has a PLU for the destination MN, it tunnels the packet to the MN's expected location.

When the MN has to send a data packet to a CN which is not in the same network, it uses its short address assigned by the GW as its destination address. The GW then replaces it with its IP address and sends it to the CN outside the network. When a packet comes from outside, the reverse process occurs.

VII NETWORK MODEL

This section evaluates the signaling overhead supported by the PSNs in a situation where the MN moves horizontally such that it associates with PSNs in different active column. This is the worst case scenario as it involves sending frequent PLU and LU to the GW leading to higher signaling overhead. Also it determines the packet loss that can occur if prediction MN's future location and buffering is not supported.

A. Network Model

Figure 4 shows the route taken by the MN inside a network. In this figure the circles identifies the association region of a PSN. Within this section, the MN associates with a PSN.

For evaluation purposes we assume the following:

1. The MNs are moving with an average speed of v and direction of their movement is between *0* to *2π*.
2. To make the calculation simple we assume that during its course of movement it needs a handover at an average distance of $\frac{\sqrt{3}}{2}R$.

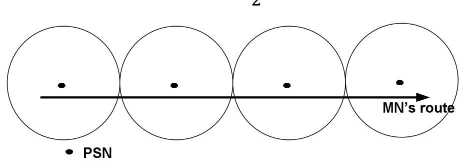

Figure 4: Network Model

For analysis of signaling cost during the MN's average network residence time we assume that it moves out of the network within *K* finite movement.

From [6], it can be seen that average number of PSN, a MN associates with (μ(K)) is rarely sensitive to change of *K* unless *K* is much smaller than *N*. Thus we assume *K* equal to *N*.

The signaling cost in the proposed solution can be broken down to:

1. The cost incurred in sending PLU messages to the GW.
2. The cost incurred in sending LU message to GW when the MN associates with a new PSN.

1. Location Update cost

$LU_{cost} = \pi_0 \times S_{LU} + \big(\mu(K-1)\big) \times (S_{LU} + S_{PLU})$ (1)

$where\ \pi_0 = \frac{1}{2}$ (2)

$S_{LU} = b_{LU} \times L$ (3) \

$S_{PLU} = b_{PLU} \times L$ (4)

Equation 1 gives the average LU cost (bits) incurred due to a MN's K movements inside the network. It includes the LU cost to the GW, associated with MN's K number of movements. Also π_0 is the equilibrium probability of the state 0 which represents the probability that the MN stays outside a given network.

B. Packet loss due to mobility (without prediction or buffering mechanism)

Incurring packet loss is a common phenomenon when a device is mobile. Here, we evaluate the packet loss (in mobile scenario) in a case where there is no prediction mechanism or buffering support provided. If Δ is the time to detect movement and τ is the time to send location update then $(\Delta + \tau)$ is the total time when a packet can be lost due to the mobility. According to proposed architecture,

$$\tau = T_{association\_request} + T_{LocationUpdate} \qquad (7)$$

Let t be the observation time and v be the speed of the MN, then total packet loss due to the mobility can be as follows,

Packet Loss = $\frac{vt}{R} \times (\Delta + \tau) \times \lambda$, where λ = packet arrival rate and R = Tx range

Again, if we consider sleep mode, a MN is forced to make a handover when its anchor finishes its active period. Thus, total packet loss can be measured as,

$$\text{Packet Loss} = \left\{\frac{vt}{R} \times (\Delta + \tau) + \frac{t}{t_{active}} \times (\Delta + \tau)\right\} \times \lambda \qquad (8)$$

Where, t_{active} is the active time of a SN.

VIII PERFORMANCE EVALUATION

The proposed mechanism can be evaluated in terms LU cost. We used the aforementioned equations to evaluate these parameters. Also the following parameters are used to obtain the results.

Table 1: Default parameters

Name	*Description*	*Value*
N	Network size	30
R	Range of IEEE 802.15.4 devices (radius)	15m
λ	Packet arrival rate	0.01 pkt/sec
b_{LU}	Signaling bandwidth (LU messages) in one hop	40 bits
L	Average number of link hops to GW	5
DA	Network Area	105m*45m
b_{PLU}	Signaling bandwidth (PLU messages) in one hop	60 bits
v	Average speed	2.0 m/s

A. Location update cost versus speed

To evaluate the location update cost and to compare it with HMIPv6, we have considered a particular path with a fixed distance between starting and finishing point. Figure 5 shows the LU cost (bits) incurred due to the MN's movement in the same path with different speed. It shows that overhead is higher for less speed. This is because of the fact that when speed is less, the MN has to perform more handoff due to sleep-active state transition of SN. But as speed increases LU cost remains constant.

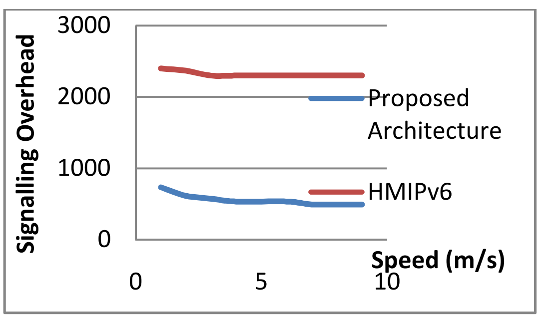

Figure 5: Location updates signaling versus speed

Figure 5 also shows that signaling overhead in bits of the proposed scheme is significantly less as compared with HMIPv6. This is due to use of adaptation layer packets for sending LU, instead of using large IP header.

B. Packet loss versus speed (no buffering or prediction mechanism)

Here, instead of fixed path length, we have considered fixed observation time with different speeds of MN.

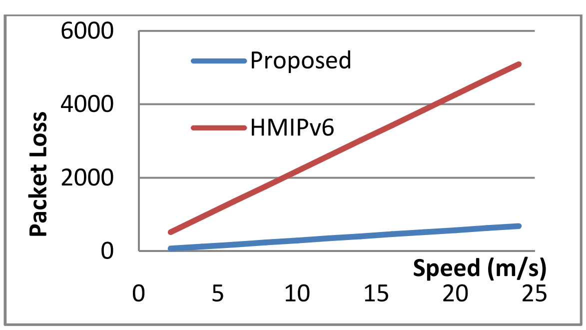

Figure 6: Packet Loss due to mobility (no buffering or prediction mechanism)

Also for HMIPv6 as the speed increases packet loss increases. This is due to the fact that with higher speed, MN has to cover more distance and has to face more handoff events. However, HMIPv6 is incurring more packet loss because; it has much higher latency for performing DAD operation during handoff event.

IX CONCLUSION

This paper provided a network assisted mobility support scheme for 6LoWPAN nodes which are extremely energy and resource constrained in nature. Through this mobility support scheme, the MNs can communicate with any node without being involved in significant amount of signaling. Neither the MN had to incorporate any major changes in its protocol stack. Moreover the scheme proposed to predict the future location of the MN and buffer its packets at SNs for short amount of time in order to in order to prevent packet loss. From the evaluation section it can be seen that the proposed scheme performs better in terms of signaling overhead and packet loss, when compared to HMIPv6.

ACKNOWLEDGEMENT

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