

ENERGY-AWARE AND BANDWIDTH-EFFICIENT MOBILITY ARCHITECTURE FOR 6LoWPAN

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ABSTRACT

This paper proposes an energy aware and bandwidth efficient mobility support architecture which handles mobility of 6LoWPAN devices, such that the communication between it and its corresponding nodes remain undisrupted. As the 6LoWPAN devices are energy and resource constrained enabling mobility in these devices with the help of conventional Host Based protocols like MIPv6 is not suitable. Moreover, it may be possible in many scenarios that the Mobile Node (MN) moves far from the Gateway (GW), while communicating with it. In this case the MN has to increase its transmission power, which may adversely affect its life time. In the proposed architecture static random deployed 6LoWPAN devices (SN) with same characteristics as the MNs, facilitate mobility such that the IP connectivity of the MN is maintained with minimum signaling at MN's end. Thus this paper describes the link layer specific mechanisms needed between the SN and the MN to help it perform multi-hop communication with the GW. Moreover, it is designed keeping in mind the energy and resource constraint nature of SNs themselves. The signaling overhead for the SNs is determined through analytical modeling.

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. The introduction of LoWPANs can be considered as the beginning of a new generation of applications. The integration of various simple devices which are able to be connected to the networks makes ubiquitous computing closer than ever to us. In order to fully realize a pervasive or ubiquitous environment, LoWPANs must be connected to the Internet Protocol (IP)-based networks. This integration would make the resource sharing possible within both networks, maximizing the utilization of available resources. Internet Engineering Task Force (IETF) is standardizing the transmission of IPv6 over LoWPANs through a working group known as 6LoWPAN [2]. 6LoWPANs are envisioned to play a major role in the future pervasive paradigm. The emerging range of 6LoWPAN applications includes consumer appliances, home automation, monitoring and control in industrial environments, military and environmental monitoring and sensing. These networks,

because of their inherent properties, provide better coverage, fault tolerance and robust behavior.

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 [4, 5] 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. Network based mobility protocol such as PMIPv6 [12] is a suitable candidate to enable mobility in 6LoWPAN devices. In PMIPv6, the gateway handles all the mobility related signaling on behalf of the MN. However the protocol assumes that the device communicates with the gateway in a single hop communication, which can severely affect the lifetime of the MNs.

This paper proposes an energy and bandwidth efficient mobility architecture which supports mobility of 6LoWPAN devices in diverse types of environments. The mobility architecture caters for the energy constraint nature of the MNs and thus enables multi-hop communication between the Gateway (GW) and MNs via some low priced static 6LoWPAN nodes. Moreover, the MNs do not require any changes in the software stack and is exempted from too much mobility related signaling. However, if a static 6LoWPAN device has to route IP packets to MN, it will be exhausted of its energy in no time. Instead we propose to utilize the reserved adaptation layer dispatch values of 6LoWPAN to help SNs identify and route packets related to MNs. Thus in the proposed architecture the adaptation layer packets are transmitted over the multi-hop links instead of IP packets. This reduces the number of bits transmitted by the SNs. Also the propose architecture is designed keeping in mind that the SNs themselves are resource constrained and thus need to periodically switch to sleep state. The performance evaluation compares the amount of signaling required by MN in the proposed mobility architecture with HMIPv6. The signaling overhead for the SNs is determined through analytical modeling. The overhead is determined against parameters like speed and packet arrival rate of the MN. Also, as the MN does not have to configure its link layer and IP layer address, every time it moves the handoff latency and packet loss is minimized in the proposed mobility architecture.

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 architecture. Section VI discusses the communication scenarios followed by mobility and the network model in section VII. Performance evaluation follows next in section VIII and finally section IX concludes the paper.

II RELATED WORK

Mobility of 6LoWPAN can give rise to new and exciting applications. Especially in the case of M-Health, 6LoWPAN sensors worn by patient can provide better monitoring scope since it is connected to the internet. In [15], authors have stressed that the most relevant technology for M-Health is technologies similar to 6LoWPAN like Bluetooth and Zigbee in terms of low cost, low-size and low power radio technology as these are the characteristics of a typical wireless sensor devices/networks.

In [14], 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.

Mobile wireless sensor without any IP ubiquity can also support numerous applications. Mobility of sensor nodes can ensure large area coverage along with the presence of more devices at the point of interest [11]. Furthermore, it can help in load balancing and filtering of local data at the node before transmission. In [7] authors proposed a model to support user mobility in WSNs. However, it does not support communication between two mobile users or nodes as they move within the sensor field

In [13] authors proposed an architecture of multi-radio enabled mobile wireless sensor network (MEMOSEN). According to them the mobile terminals with multiple radio transceivers can act as either a sensor or a sink node. However as most of the sensor nodes and 6LoWPAN nodes is still short range and does not support such technology.

In [3] authors have proposed an interoperable architecture between NEMO and 6LoWPAN to support network mobility. They have suggested an extended routing scheme for mobile routers to support mobility in 6LoWPAN sensor nodes. However the architecture does not cater for individual node mobility.

The host based mobility protocols like MIPv6, FMIPv6 and HMIPv6 was proposed by Internet Engineering Task Force [2]. 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 [5]. 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. Moreover, these protocols demands a complex host stack, which is not feasible for 6LoWPAN considering their inherent constraints.

Network based localized mobility like PMIPv6 [12], also proposed by IETF, is where the network side performs the mobility-related signaling on behalf of the MN. NETLMM introduces several new entities like Localized Mobility Anchors (LMA), Mobile Access Gateway (MAG) etc. These entities together detects the MN's movement, sets up the data path to enable the MN to use its home address from communication from the access link, emulates MN's home link on the access link. The interface between the MN and MAG is defined at the IP layer and is applied to single hop. However single hop communication is not suitable for 6LoWPAN devices. In contrast this paper describes the link layer specific mechanisms needed between the SN and the MN to help it perform multi-hop communication with the GW.

III MOBILITY REQUIREMENTS IN 6LOWPAN

One of the possible scenarios, which require mobile 6LoWPAN devices, is when they are used for monitoring purposes like monitoring of heart beat, temperature and pulse rate of patients moving within the hospital building. In this case, every room will have SNs deployed, which will help the MN to communicate with the GW. Mobility requirements in 6LoWPAN include [11]:

1. Providing fast handover detection.
2. The mobile devices 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

IV SYSTEM MODEL AND ASSUMPTIONS

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

1. A MN is an active device which is moving between multiple GWs.
2. The current velocity of the MN is strongly dependent on its previous velocity.
3. The GWs are interconnected with each other through wireless or wired links.
4. The area under the interconnected GWs is referred to as a domain.

5. The SNs in the proposed architecture are densely deployed to an extent that their transmission and sensing ranges overlap.
6. IEEE 802.15.4 networks provide two types of addresses, IEEE EUI64-bit extended address and 16-bit short addresses.
7. The SNs are assigned with IPv6 address and with 16 bit short address. These nodes are associated with one of the GWs.
8. The IP address of the MN and 16-bit short address or MN ID remains the same irrespective of its location in the domain.
9. Each 6LoWPAN device has the same transmission signal strength and receiver sensitivity.
10. Each SN measures the distance between itself and the target based on the received signal strength (RSSI) [6].
11. Each SN is equipped with a radio-triggered hardware component that activates sensors from/to the sleep state, by sending a special wake up radio signal [8].
12. The interoperability between IPv6 domain and the IEEE802.15.4 device is handled by the adaption layer [9].

V MOBILITY SUPPORT ARCHITECTURE

Any proposed mobility support architecture should be such that only network side changes are required to support 6LoWPAN device mobility. The device themselves does not have to perform any software upgrade.

V.I Operational Architecture

In the proposed architecture the GW, SNs and the MNs have the following roles.

Gateway: In the proposed architecture it is assigned additional functionalities like sending Binding update and storing bindings of the MNs in order to provide mobility support to the 6LoWPAN nodes. The detail functionalities of GW are given below.

1. *Protocol Translation:* Since in the proposed architecture the static 6LoWPAN nodes are helping in routing data packets to or from the MN, it is more appropriate not to transmit IP packets over multi-hop link. Instead IEEE802.15.4 frames encapsulated in adaptation layer header can be transported over wireless link. The GW thus fragments IP packets before sending it to the MN and assembles the adaptation layer packets into an IP packet before sending it to the correspondent node (CN) outside the domain.
2. *Address Translation:* This architecture proposes to use 16-bit short address for the entire static and MN. Thus the GW has to translate the 16 bit short address to an IP address.
3. *Storing Bindings of the MN:* As seen from figure 2 the GWs keep a binding table which maps the MN's ID, its current location, Home address, and CN's IP address.

4. *Binding update to other GWs:* When a MN enters the domain for the first time; the GW has to send a Binding Update (BU) to the MN's home agent and also to the CNs if required. Also if it is connected to multiple GWs, the current gateway has to inform the other GWs about the MN's new location.

Static nodes: The static nodes in the proposed architecture are deployed under different GWs to do the following tasks.

1. *Predicting the future location of the MN:* As the SNs are themselves resource constrained, they spent most of their time in sleep state. When a MN associates with a SN, the associated SN keeps a track of MN's movement. It then activates the next SN in sleep state with which the MN can associate depending on the direction of its movement.
2. *Indicating to the MN that it has moved:* When the old SN activates the new SN, it transmits *Hello_packets* at certain intervals. The *Hello_packet* contains SN's short address which enables the MN to determine that it has moved.
3. *Sending Location Update to the GW:* When the old GW activates the new SN, the new SN sends a LU to the GW. This helps to route data packets to the MN.
4. *Routing of MN's data packets:* The SN also route MN's data packets. Any energy efficient routing schemes can be used to route data packets [16, 17].
5. *Forwarding the MN's packet to the new location:* The old SN keeps forwarding the MN's packet until the LU message from the new SN reaches the GW.

Mobile node: When it receives an indication that it has moved, in form a *hello_message* it sends an *association_request* message to the new SN.

V.II MN entering the Domain

Figure 1 shows a domain with different GWs which are interconnected and the MN is moving within the domain. The SNs at the boundary of the domain are in a quasi sleep state. Thus, their sensor is turned on whereas their transceiver and processor is switched off. When the SN senses a MN, it wakes up from quasi sleep state to active state. In active state it periodically transmits a *hello_packet*. When a MN enters the domain for the first time it scans the entire frequency channels to receive a *hello_packets* from a SN.

Once it receives a *hello_packet*, it sends a *join_request* packet to the SN from which it received the *hello_packets*. The *join_request* message contains MN's Home address, and its entire CN's IP address. The SN 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) to the MN. Also it maps the CN's IP addresses into unique short address in order to save the communication cost. It then sends the MN's ID and its CN's mappings to the SN in form of a *join_confirm* message. The SN then informs MN of its newly assigned ID along with the mappings of the IP addresses and short addresses of its CNs. Also GW stores mapping of the MN's ID, it's HoA and its current associated SN's short address along with its CN's short address and their

IP address. It then sends a BU to the Home Agent, CNs of the MN along with the other GWs of the domain.

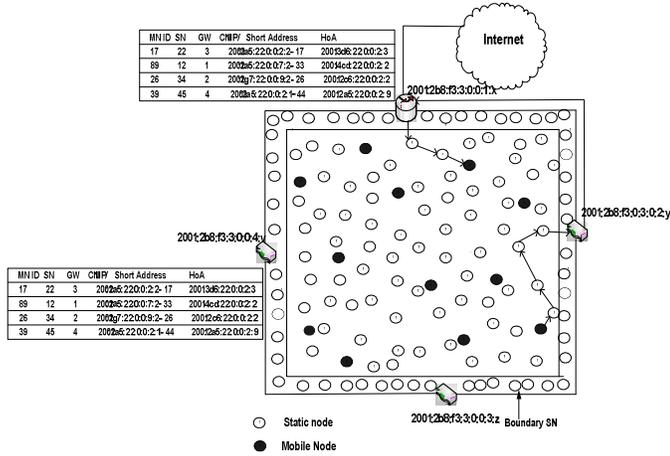


Figure 1: Network model

V.III Handoff Support

Once the associated SN (with which a MN is currently associated) observes that their link quality has degraded beyond a certain threshold, it assumes that the MN is moving. Hence the current SN needs to activate the next appropriate sensor node for the handoff process. In order to activate the next appropriate SN, the associated SN must know the direction where the MN is moving. The direction can only be found through localization procedure, where a series of MN's locations depict its course of movement, i.e. tracking. There are various methods to obtain mobile node location like, trilateration/triangulation method, AOA (angle of arrival) and ToA / TDOA (time {difference} of arrival) method, signal strength indicator etc.

To enable the SN to determine the direction of movement, we propose to use AoA method. AOA is defined as the angle between the propagation direction of an incident wave and some reference direction, which is known as orientation. Orientation, defined as a fixed direction against which the AoAs are measured, is represented in degrees in a clockwise direction from the North. When the orientation is 0° or pointing to the North the AoA is absolute; otherwise relative. We assume that each sensor node is equipped with an antenna array in order to obtain AOA measurements.

Figure 2 describes the next node activation process in our approach. As shown in Figure 5, 'the star' shows MN position at time-stamps TS₁, TS₂ and TS₃ respectively. The associated SN measures the AoA from the signal that it receives from the MN. Moreover the associated SN also estimates the distance between the MN and itself, using received signal strength of the packets.

As shown in Figure 3, $\alpha_1, d_1; \alpha_2, d_2; \alpha_3, d_3$ be the angles (in degrees) and the distances between the associated node and the MN, at time-stamps TS₁, TS₂ and TS₃ respectively. Based on angle and distance information, the sensor node can obtain MN'S location coordinates. At the time-stamp TS₃, the SN

awakes the next SN from sleep state (represented as II in Figure 3) for the handoff. Also it sends a *new_node* message to it, which contains MN's ID.

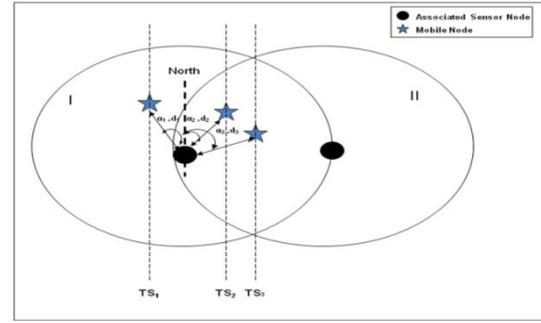


Figure 2: Next node activation Process

When the new node receives the *new_node* message it transmits a *hello_packet* at some intervals. It also sends a LU to the GW. Upon receiving the *hello_packet*, the MN sends an *association_request* packet to the new SN. When the new SN receives the *association_request*, it again sends a *new_node* message to the old SN. From the time the old SN receives the *new_node* message, it starts to forward the MN's packets to the new location till the LU reaches GW. After the LU reaches the GW, it forwards the MN's packets to the new location. As soon as the MN's packets stop arriving at the old SN, the SN switches to a sleep mode after a specified interval of time. The handover support mechanism is support in figure 3.

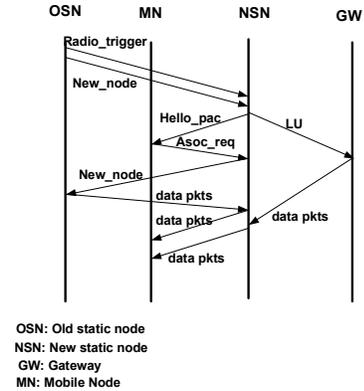


Figure 3: Handoff Support

In order to differentiate different kinds of mobility messages exchanged between nodes we propose to utilize the adaptation layer's reserved dispatch values [9]. Every adaptation layer packets begins with a dispatch value which identifies what kind of header is following. The dispatch value is a 8 bit value that indicates what kind of packet is it. For example a dispatch value 01 000001 indicates that the following header is an uncompressed IPv6 header.

Thus in this architecture we propose to identify mobility related packets with the use of specific dispatch values. The dispatch values of some of messages are shown in table 1 below.

Table 1: Dispatch values

Dispatch value	message
01 000011	Join_request
01 000111	Association_req
01 001111	Hello_packet
01 111110	New_node
01 011011	Location_update
01 101111	Data packets for MN

VI COMMUNICATION SCENARIOS

Figure 1 show two MNs associated with two different gateways communicating with each other. 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 a SN receives the packet, it checks whether the MN is associated with it or not. If not, then it discards the packet otherwise it forwards the packet to the node closer to the GW. The message format is shown below.

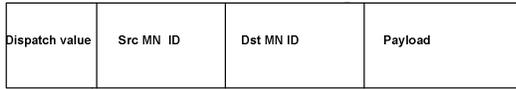


Figure 4: Data packet from MN to GW

When the data packet reaches the GW, it checks whether the destination MN is associated with it one of its SNs or not. If it is associated then creates a bidirectional tunnel between itself and the SN and transfers the packet. If the destination MN is associated with some other gateway, then GW tunnels the packet to destination GW, which then forwards the MN. If the source and the destination are located near each other and if mobility is low for both source and destination MN, then GW can update the SN of the source MN with the short address of the destination MN's SN. The Source SN can then tunnel the packet to the destination SN. In case, any one of the MN moves, the MN's associated SN informs the SN about it.

When the MN has to send a data packet to a CN which is not in the same domain, 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 domain. When a packet comes from outside, the reverse process occurs.

VII MOBILITY AND NETWORK MODEL

We use the fluid flow mobility model. In that case the binding update pattern of a MN can be modeled using a continuous-time Markov Chain. The states in the Markov chain identify the number of SNs with which the MN associates in a given domain. Transition $b_{2,0}$ indicates that a MN associates with two SNs and then move out of the domain.

In figure 5 shows a possible route taken by the MN inside a domain. In this figure the squares identifies the association region of a SN. Within this square, the link quality between the MN and the SN is above a threshold. When the MN

crosses the square, it associates with another SN from which it receives a *hello_packet*.

For evaluation purposes we assume the following:

1. A domain is composed of N equal squares that are equal in size and form a contiguous area.
2. The MNs are moving with an average speed of v and direction of their movement is between 0 to 2π .

For analysis of signaling cost during the MN's average domain residence time we assume that it moves out of the domain within K finite movement. From [10], it can be seen that $\mu(k)$ (average number of SN, a MN associates with) 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 LU messages to the gateway and the cost of sending *new_node* messages, every time a MN associates with a new SN.
2. The cost incurred in tunneling data packets from the gateway to the SNs of the destination MN. The default parameter value is given in table 3.

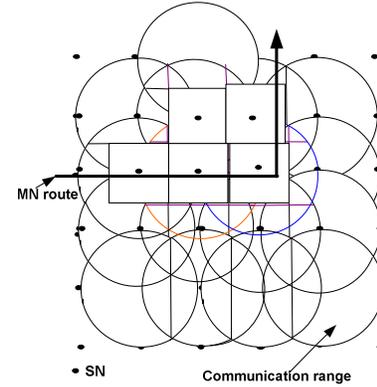


Figure 5: Network Model

In table 2 the signaling bandwidth in bits for location update is the size of the dispatch header (8 bits) plus the 16 bit address of the SN plus 16 bit MN ID.

Table 2: Default parameters

Name	Description	Value
N	Domain size	12
R	Range of IEEE 802.15.4 devices (radius)	15m
λ	Packet arrival rate	0.001 pkt/sec
b	Signaling bandwidth (LU messages) in one hop	40 bits
t	Signaling bandwidth (tunneling cost) in one hop	16 bits
L	Average number of link hops to GW	3
DA	Domain Area	105m*45m
v	Average speed	0.1m/s
S	Signaling bandwidth (new_node) in one hop	56 bits

Similarly extra 16 bits are required in tunneling the packet due to the MN in the proposed architecture.

1. Location Update cost

$$LU_{cost} = \pi_0 \times S_{LU} + (\mu(K) - 1) \times S_{LU} + (\mu(K) - 1) \times S \times 2 \quad (1)$$

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

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

Equation 1 gives the average LU cost (bits) incurred due to a MN's K movements inside the domain. It includes both the LU cost to the GW and cost to send new_node message, 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 domain. In this case we assume that the probability of MN staying outside the domain is same as staying inside.

2. Tunneling cost

$$TU_{cost} = \lambda \times T_{as} \times \mu(k) \times S_r \quad (4)$$

$$S_r = t \times L \quad (5)$$

In the above equation, λ is the average packet arrival rate to a SN when it is connected to a parent node. The time for which a MN remains connected to a SN can be referred to as T_{as} and can be given as [10]:

$$T_{as} = \frac{\sqrt{(\pi A)}}{2v} \quad (6)$$

Where, A is the area of the square shown in figure 7.

VIII PERFORMANCE EVALUATION

This section provides a comparison between HMIPv6 and proposed architecture in terms of number of signaling needed at the MN's end. Also it evaluates the signaling overhead in bits with respect to speed and packet arrival rate.

VIII.I Signaling comparison between Proposed Architecture and HMIPv6

In the table 3 it can be clearly seen the MN is exempted from most of the mobility related functionalities like sending BU to home agent, CN and local home agent. The local home agent in this case is the GW. Also the MN does not have to configure its link layer and IP layer from the advertised prefix. The network does all that for the MN. Moreover since the link layer and the IP layer address is not changing every time the MN moves, the handover latency is small compared to other mobility protocols like MIPv6 and HMIPv6.

Table 3: Signaling comparison between proposed architecture and HMIPv6

Functionalities required by MN	HMIPv6	Proposed Architecture
Sending BU to HoA and CN	Yes	No
Sending Local BU to MAP/GW	Yes	No
Forming LCoA	Yes	No

The proposed mechanism can be evaluated in terms LU cost, tunneling costs with respect to speed of the MN, the no. of hops the packets travel (LU and data packets) and packet arrival rate. Also the network energy consumption is evaluated with respect to speed of the MN.

VIII.II Location update cost versus speed

Figure 5 shows a possible path followed by a MN as it enters a domain. Figure 6 shows the LU cost (bits) incurred due to the MN's movement in the same path with different speed. It shows that as speed increases LU cost does not change. This is due to the fact that even if the speed of the MN increases, it associates with same number of SN which comes in its path and thus sends same number of binding update messages.

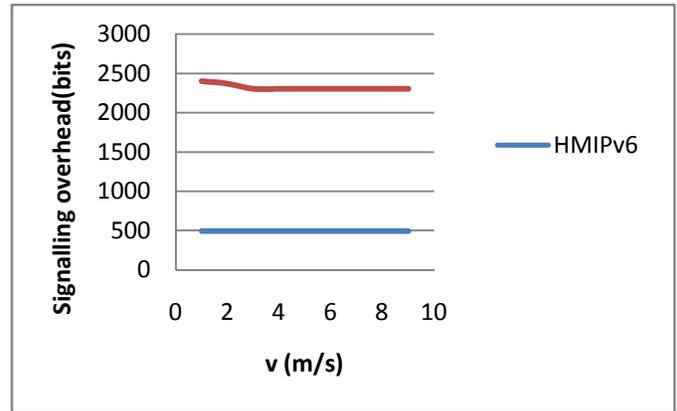


Figure 6: Location updates signaling versus speed

Figure 6 also shows that in HMIPv6 the location update cost lessens with increase of speed as the amount of binding refresh reduces. Moreover it can be seen that the signaling overhead in bits of the proposed architecture is significantly less as compared with HMIPv6. This is due to use of adaptation layer packets for sending LU, instead of using IP as in the case of HMIPv6.

VIII.III Tunneling cost Vs Packet arrival rate

Packets are tunneled from the gateway to the destination MN's SN. According to equation 4, the tunneling cost increases linearly as the number of packets that arrives for a MN in a unit time, increases. However from figure 7 it can be seen that tunneling cost of the proposed architecture is still less compared to HMIPv6 as in HMIPv6 additional signaling bandwidth consumption generated tunneling per packet is equal to the size of an IPv6 header.

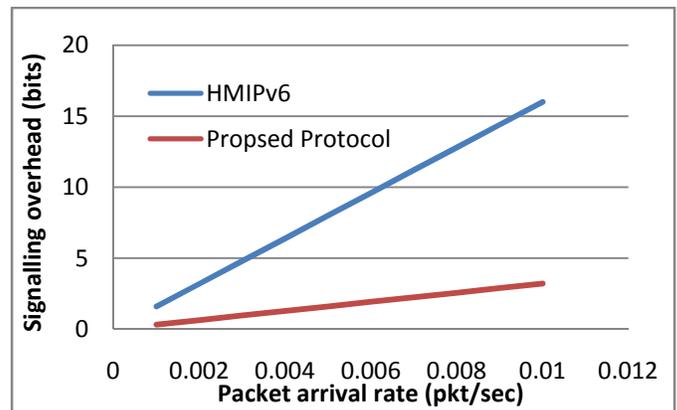


Figure 7: Tunneling cost Vs packet arrival rate

VIII. IV Network energy consumption Vs speed

We have benchmarked the energy model as explained in [18], which measures the network energy consumption over time. We have measured the total network energy consumption by varying the speed of the MN over different network bandwidths. In order to increase the bandwidth the SN need to operate at higher frequency by increasing reception/transmission power. This results in more energy consumption. Moreover as the speed of the MN increases, the SN finds less time in sleep mode; resulting more network energy consumption. The efficacy of our proposed approach can be seen from Figure 8. When the bandwidth of the network is increased upto four times, then the network energy consumption is increased twice only. At the other hand, linear network energy consumption is observed with the increase of MN speed. Because when the MN is moving fast, then handover association with the next SN will occur more frequently. This causes more energy consumption as compared to the slow speed MN, where it keeps association with the SN for a long time period and follows almost same routing path towards the GW. Note that, here we are measuring the overall network energy consumption. Thus frequent handoff and MN association with SN causes consumption of more energy consumption.

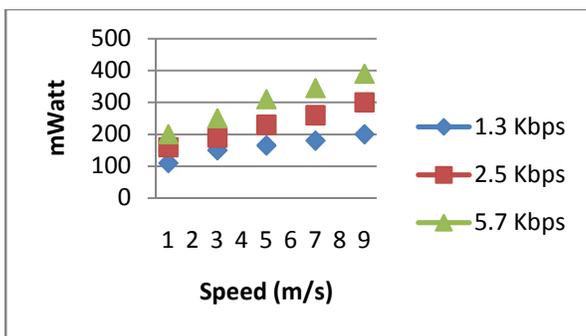


Figure 8: SNs power consumption with variable MN speed on different network bandwidths

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 architecture, 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 since the MN does not have to reconfigure its short address or its IP address every time it moves; hence the handover latency in both second and third layer is greatly reduced. This reduces packet loss as well. Since adaptation layer data packets are transmitted, instead of IP layer directly over multi-hop link, it greatly reduces the bandwidth consumption as compared to transmitting IP directly to the MNs (as seen in the performance evaluation section).

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