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Mobility of IP based Wireless Sensor Nodes in Sensor-Grid infrastructure

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Abstract- As the world is moving towards the "Internet of Things" [1], Internet Protocol enabled wireless sensor network is becoming an important research area. In order to make it possible and to facilitate transmission of IPv6 packets over low powered networks, 6Lowpan [2,3] has been introduced. Since the IP-WSN application domain is expanded to real-time applications such as health-care [17] and surveillance systems, a fast and seamless handover becomes an important criterion for supporting mobility in 6LoWPAN [21]. In this paper, we have studied mobility characteristics along with design issues under different mobility scenarios. We propose a scheme to manage the mobility of nodes. The 6LoWPAN based wireless sensor network will be integrated with grid computing establishing a Sensor-grid which may also be used widely in various applications.

Index terms***:*** **WSN; Internet of Things; 6LoWPAN; Mobility; Sensor-grid;**

I. INTRODUCTION

In the modern world, many applications based on Wireless Sensor Network (WSN), like patient health monitoring, home automation etc. [23] [24], require extensive use of Internet. Therefore, in order to realize the full potential of WSN through the Internet, integration of the two technologies is needed and the integration must comply with the current and existing standards. The end-to-end communication in WSN can be achieved by using a common network protocol working on top of different link technologies (e.g. Wi-Fi, Ethernet and 802.15.4). The usage of an open standard interface such as Internet Protocol (IP) as the common networking layer provides greater robustness and flexibility to the system [5]. In addition, IP provides transparency for host and servers in the network and eliminates the need for using gateways which may be required for interfacing a ZigBee network with the Internet. Unique addressability of various kinds of devices (sensor devices, PDAs, laptops etc.), seamless connectivity as well as wide applicability are also supported [6]. For making the use of IP in a WSN environment, we use 6LoWPAN which defines encapsulation and header compression mechanisms and allow IPv6 packets to be sent to and received from over IEEE 802.15.4 based networks [7].

IP based Wireless Sensor Networks present new challenges when compared with traditional computer networks. One of the major challenges is the mobility of the sensor nodes. In an indoor environment, some nodes may be mobile and static nodes may be deployed strategically to gather data from the mobile nodes. The challenge here is to continue data transmission from the mobile nodes to static nodes in an uninterrupted manner.

This research aims at using Sensor-Grid infrastructure in health-care applications [4]. Hence, it is assumed that sensor nodes are assigned to patients and static nodes are deployed strategically for retrieving health-data from the patients. Each of these static nodes forms corresponding PANs. Patients are supposed to carry these sensor nodes with them to facilitate continuous health monitoring [17]. A patient may walk around his own ward or he may be wheeled around different locations within the health-care center. Eventually, they may come across various static nodes which will result in moving around different PANs. During this process, transmission of patient data may be interrupted in the absence of proper mobility scheme. Therefore, mobility management of the sensor nodes is very much required within this sensor-grid infrastructure.

Mobility based communication increases the fault tolerance capacity of the network [18] and prolong the lifetime of devices and increases the connectivity between nodes and clusters. Using distributed LoWPANs, it is possible to sculpt the devices to cluster around areas of interest, cover large areas, and work more efficiently by filtering local data at the node level before it is transmitted [22]. Furthermore, multiple controlled mobile elements can be used to provide load balancing and gathering data. In this paper the mobility issues in a 6LoWPAN environment are studied and a scheme is proposed to manage the mobility of nodes based on received signal strength and link quality.

Rest of the paper is organized as follows. Section 2 discusses the related work. Section 3 describes the characteristics of mobility in a WSN. In Section 4 & 5, 6LoWPAN is described and mobility scheme design issues in this environment are discussed. Section 6 describes different mobility scenarios. A mobility scheme is proposed in Section 7. Implementation of the scheme is described in Section 8. The evaluation results of the scheme are discussed in Section 9. Finally we conclude in Section 10 with a direction for the future work.

II. RELATED WORK

While making a survey on the mobility support in 6LoWPAN network, it is found that most research works which focus on proposing mobility schemes in 6LoWPAN environments adopt an analytical approach while evaluating different schemes. Few schemes are evaluated by simulation also. In [14], inter-pan mobility support for 6LoWPAN is discussed and a simulation is done for the scheme presented. The mechanism is evaluated in terms of location update cost versus speed. Network assisted mobility for 6LoWPAN is presented in [15]. The proposed scheme helps to predict the future location of the moving node and buffer its packets for short amount of time in order to prevent packet loss. In [16], MIPv6 is used to design a mobility and fault-tolerance model where fixed IPv6 addressing is used to avoid reconfiguring IP addresses when moving node changes network.

In contrast with the theoretical analysis carried out by other researchers [14][15][16], we implement a scheme for mobility management in this paper. This scheme manages intra as well as inter-pan mobility. TinyOS is used to implement the scheme onto the wireless sensor nodes. The scheme for moving nodes is divided into two approaches – the first one is a time driven approach and the second one is a message driven approach. Both of these approaches may be applicable to specific applications with mobility feature. Also, functionalities of Edge Router to support the mobility is described and implemented so that mobility and hand-over process become seamless.

III. CHARACTERISTICS OF MOBILITY

Wireless Sensor Networks are not address driven like traditional networks, rather these networks are data-driven and. It is important to receive the sensor readings of an area, but this data may not come from a specific device. The main application of a sensor network is to get the sensor reading of a particular area. Thus, the mobile nature of sensor nodes should be transparent to the application level as the application should bother about data and not about the data source [20]. So when sensor nodes are moving, they should continue the work of sensing and sending data to the place of requirements. Characteristics of mobility in WSN may be summarized as follows:

- Mobility is intentional and can be predicted and controlled.
- It helps to improve coverage of WSN.
- Mobility enabled WSN improves ability to cope with node failures.
- Mobility can help to recover link maintenance which can restore an isolated sub part of a network.
- With the help of mobility management, sensor nodes can harvest or store limited power that may be dissipated.
- Localization can be optimized by mobility strategies.
- Mobility enhances man-machine interaction.

As we have implemented the mobility schemes in 6LoWPAN, brief discussions are made about it in the following section.

IV. 6LoWPAN

IPv6 over Low-power Wireless Personal Area Networks is commonly known as 6LoWPAN. It was conceptualized by Internet Engineering Task Force (IETF). It is designed on IEEE 802.15.4-2003 standard. The IPv6 packet transmission in 6LoWPAN is challenging because of the low capabilities in terms of processing, bandwidth and memory of 802.15.4 devices. The 6LoWPAN format defines how IPv6 communication is carried in 802.15.4 frames [2]. IPv6 solves the problem associated with IP address space from 32 bits to 128 bits and minimum MTU (Maximum Transferable Unit) of IPv6 is 1,280 bytes that is ten times the one specified for 802.15.4 networks, as a result the IPv6 adoption as network layer protocol does not fit with its MTU specifications. The 40 bytes length of IPv6 header also creates a huge overhead. To overcome the MTU requirements of IPv6 and header overhead, 6LoWPAN implements an adaptation layer between network and data link layers [3]. The adaptation layer provides fragmentation and reassembling of IPv6 packets as well as header compression. Fragmentation of the IPv6 datagram is required for the MTU specification of the 802.15.4 standard, while the header compression is necessary to reduce the header overhead.

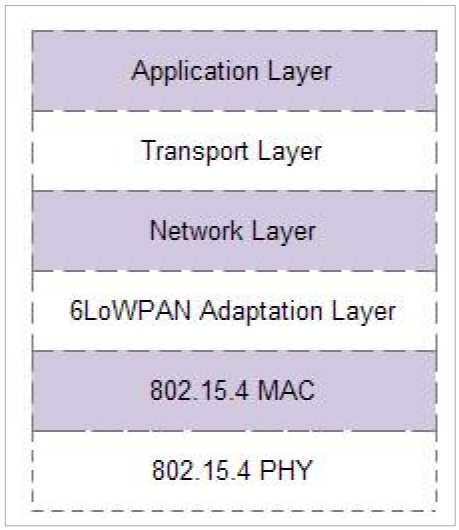

Figure 1 : 6LoWPAN layered stack [3]

IPv6 nodes are assigned 128 bit IP addresses in a hierarchical manner, through an arbitrary length network prefix. IEEE 802.15.4 devices may use either of IEEE 64 bit extended addresses or, after an association event, 16 bit addresses that are unique within a PAN. There is also a PAN-ID for a group of physically collocated IEEE 802.15.4 devices. The IPv6 link-local address for an IEEE 802.15.4 interface is formed by appending the Interface Identifier to the prefix FE80::/64.

V. MOBILITY SCHEME DESIGN ISSUES

6LoWPANs have unique low-performance properties where the devices are with highly reduced memory and power. So, new challenges arise when the nodes become mobile. It is crucial to reduce the additional mobility related signaling overhead or to possibly avoid it altogether [19]. Especially to optimize power consumption, battery powered devices should be correctly discovered and handled by more capable (and possibly mains-powered) devices in the network, such as the Edge Routers [21]. The fundamental goals for mobility support in 6LoWPANs can be listed as follows [8]:

a) Mobile 6LoWPAN nodes must be addressable by any corresponding node, independent of the current whereabouts. Global addressing should be supported.
b) Mobility related signaling for nodes should be reduced, as much as possible.
c) Fast handover detection should be supported.
d) Mobile 6LoWPAN devices should change their location while being in state of hibernation.
e) Existing mobility protocols should be re-used, if possible.
f) Fragmentation must be avoided for signaling messages.
g) Star topology as well as mesh topology must be supported.

VI. MOBILITY SCENARIOS

In 6LoWPAN network, each Edge Router forms a PAN with few other nodes and the Edge Router acts as sink node of the concerned PAN. In this discussion, we assume that the Edge Router remains static one. So, network mobility is beyond the scope of this paper. 6lowpan uses flat address space which means that all nodes within one certain subnet share the same IPv6 prefix [2]. Mainly two different mobility scenarios may occur for the nodes.

A. Intra-PAN mobility

A node may move around within the periphery of a single PAN. This movement may be termed as intra-pan mobility of the concerned node. It is also called 'micro' mobility where IPv6 prefix remains same for the moving node. In this mobility, the moving node updates its current location while keeping the radio link with concerned Edge Router alive.

B. Inter-PAN mobility

If a node moves from one PAN to another PAN, it will be inter-pan mobility of the concerned node. This movement requires selection of a new Edge Router in the new pan where the node moves into. So, it involves change in IPv6 prefix of the concerned node. It is also termed as 'macro' mobility.

VII. PROPOSED MOBILITY SCHEME

In this section, we propose a mobility scheme in 6LoWPAN network. The scheme is described in two subsections for the moving nodes and the static Edge Routers respectively. Before that, we briefly discuss two important metrics which will be referred in the mobility scheme later on.

A. Received signal strength indicator

The RSSI is a 5-bit value indicating the receive power in the selected channel, in steps of 3 dB. No attempt is made to distinguish between IEEE 802.15.4 signal and other signal source, only the received signal power is evaluated. Using the Basic Operating Mode, the RSSI value is valid at any RX state, and is updated every 2 µs. The current RSSI value is stored to the PHY_RSSI register.

The PHY_RSSI is an 8-bit register, however, the value is represented in the lowest five bits [4:0] . An RSSI value of 0 indicates an RF input power of < -91 dBm. For an RSSI value , the RF input power can be calculated as follows [9]:

$$P = RSSI\_VAL + RSSI\_OFFSET \text{ [dBm]} \qquad (1)$$

where the RSSI_OFFSET is approximately –45. It is found empirically during system development from the front end gain. If reading a value of –20 from the RSSI register, the RF input power is approximately –65 dBm.

B. Link quality indicator

The IEEE 802.15.4 standard defines the LQI measurement as a characterization of the strength and/or quality of a received packet. The use of the LQI result by the network or application layer is not specified in this standard. LQI values shall be an integer ranging 0 to 255.

The LQI values can be associated with an expected packet error rate (PER). The PER is the ratio of erroneous received frames to the total number of received frames. A PER of zero indicates no frame error, whereas at a PER of one no frame was received correctly.

The minimum and maximum LQI values (0 and 255) should be associated with the lowest and highest quality compliant signals, respectively, and LQI values in between should be uniformly distributed between these two limits. It may be calculated as follows [9] :

$$LQI = (CORR - a) \cdot b \qquad (2)$$

where a and b are found empirically based on PER measurements as a function of the correlation value (CORR).

A low LQI value is associated with low signal strength and/or high signal distortions. Signal distortions are mainly caused by interference signals and/or multi-path propagation. High LQI values indicate a sufficient high signal power and low signal distortions.

It is to be noted that the received signal power as indicated by received signal strength indicator (RSSI) value does not characterize the signal quality and the ability to decode a signal. For higher signal power levels the LQI value becomes independent of the actual signal strength. This is because the packet error rate in these scenarios tends towards zero. Thus, further increase of the signal strength (i.e. by increasing the transmission power) does not decrease the error rate any further.

6LoWPAN networks require to determine the best route between two nodes. Both, the LQI and the RSSI can be used for this, depending on the optimization criteria. As a rule of thumb, RSSI is useful to differentiate between links with high LQI values. Transmission links with low LQI values should be discarded for routing decisions even if the RSSI values are high.

C. Scheme for Node Router:

Due to the mobility of nodes, communication link with corresponding Edge Routers may be broken. Therefore, certain values of RSSI and LQI are set to define as the threshold for a good link. When the threshold value is reached, the moving node initiates a search for other prospective Edge Routers (ER) in order to avoid isolation from the network. The pseudo-code depicted in Figure 2 describes the scheme for the moving nodes and Figure 3 represents the route table which is maintained by moving nodes.

```
bind_edge_router() {

while (trigger_th() == 1) do
{
// Moving node detects threshold for good communication link is triggered

        broadcast( solicitation_msg, node.ip);
// Node broadcasts solicitation message for selecting new Edge Router
// node_ip is the address of the moving node

/* after receiving solicitation_msg nearby Edge Routers revert back to the node with adv_msg */
        recv(adv_msg,er.ip);

er_RSSI= get_RSSI(adv_msg);
// moving node obtain RSSI of adv_msg
er_LQI= get_LQI(adv_msg);
// moving node obtain LQI of adv_msg

if  (th_RSSI > er_RSSI && th_LQI > er_LQI)
        // moving node checks RSSI and LQI of adv_msg
                continue;
        else
/* moving node checks whether IPv6 prefix of incoming adv_msg is same that of its solicitation_msg
*/
        if( chk_IPv6_prefix(adv_msg, solicitation_msg) == 0)
                update_node_route_table();
/*  moving  node  updates  its  route  table  with  Edge  Router  address  (er_ip)  along  with  the
corresponding RSSI (er_RSSI) and LQI (er_LQI) values */
} //end of while loop

new_er= select_edge_router();
// select_edge_router() returns the ip of the selected Edge Router
/* moving node now selects an Edge Router from the route table which has maximum RSSI value.  If
two Edge Routers have same RSSI value, then the Edge Router with better LQI is prioritized */
send(binding_req_msg, new_er.ip);

/*moving node sends binding information to the UDP socket port of the newly selected Edge Router
(new_er)*/

recv(ack_msg, new_er.ip);
/* upon receipt of acceptance, moving node sends release message to current Edge Router */

send(release_msg, curr_er.ip);

update_IPv6_prefix(new_er.ip); //updates its IPv6 prefix with that of the new Edge Router */

send(ack_msg, new_er.ip)l
//moving node acknowledges newly selected Edge Router upon successful binding

} //end
```

Figure 2 : Pseudo-code for mobility scheme of nodes

er.ip	er_RSSI	er_LQI

Figure 3 : Route table structure for moving nodes

While moving, Node Router (NR) checks the RSSI of the link with Edge Router (ER) concerned. Based on the Node Router's checking of signal strength, the scheme for moving nodes is bifurcated into two approaches:

i. Timer driven.

ii. Message driven.

i) Timer driven approach

The heart of this approach is the timer event which is fired periodically. Signal strength of ER is checked after certain period (TIME_PERIOD). The challenge is to define the TIME_PERIOD. It should depend on how frequently a node changes its position. If a mobile NR changes its position frequently, TIME_PERIOD should be less because NR may go out of bounds of ER. However, this measure is application specific. Further this approach is more appropriate where the stay-period of a NR in a particular PAN is predictable.

The approach can be described in the following steps. Also Figure 4 presents a sequence diagram for the same.

- A TIME_PERIOD is set for checking RSSI.
- Upon triggering of the timer event NR sends solicitation messages to the Edge Routers which are in the vicinity.
- ER reverts back to the NR with router advertisement.
- NR checks whether the received advertisement reached the threshold value of both RSSI & LQI and stores details of ER in a table.
- NR searches the table for ER with highest RSSI and sends binding request along with its IP.
- After receiving the request, ER binds the node with it and stores details in a table.
- ER prints the IP address of newly associated NR.

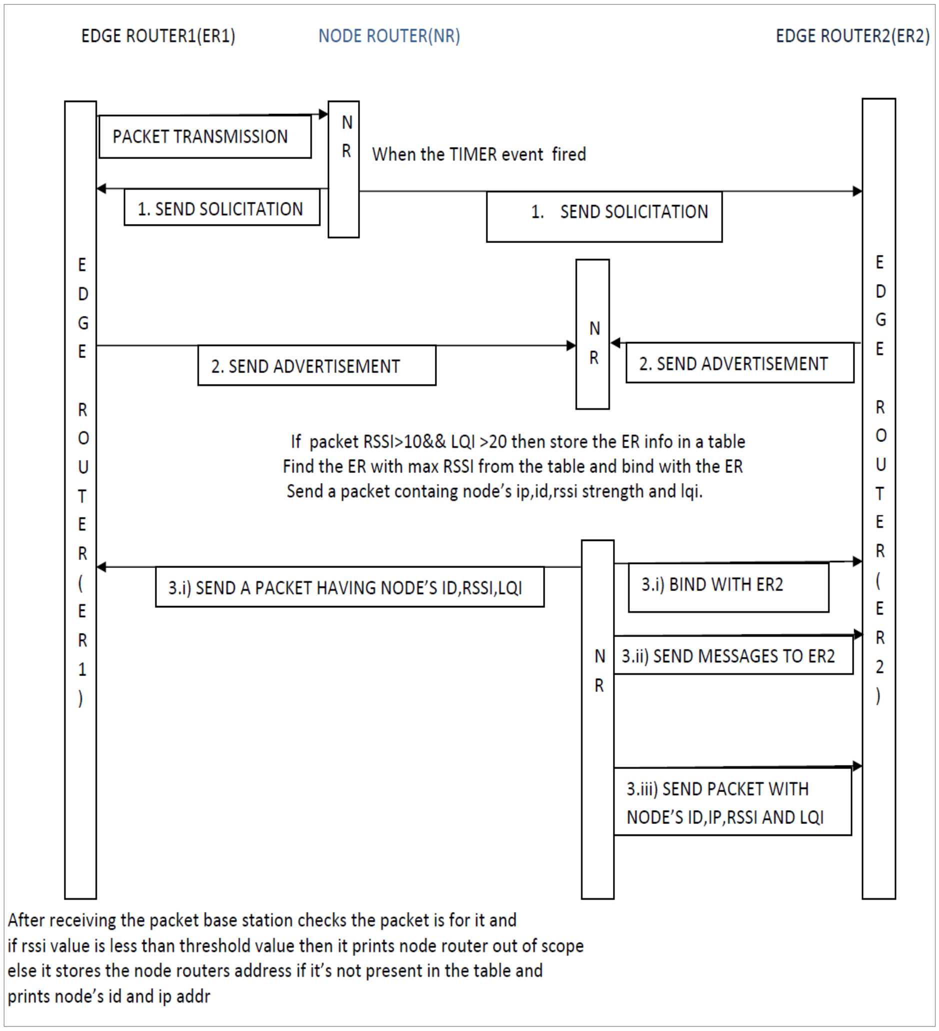

Figure 4 : Sequence diagram of message passing in Timer Driven approach

ii) Message driven approach

This approach is based on the signal strength of the received message from Edge Router. When the signal strength falls under a certain threshold value, a search for new Edge Router will be triggered. The main problem with this approach is that the Node Router need to check every incoming message for signal strength, leading to inefficiency in time and energy. Therefore, to do away with this problem, it is proposed to define a 'SESSION'. Here SESSION is nothing but a time-period. During this time-period Node Router is not supposed to check the signal strength or link quality from incoming messages. The SESSION may depend on certain heuristic. In this paper the following heuristic has been used. The length of the SESSION is defined as a function of the three previous values of signal strength (RSSI).

$$SESSION_i = f\,(RSSI_i,\ RSSI_{i-1},\ RSSI_{i-2}) \qquad ...(3)$$

When the signal strength increases or stabilizes, it signifies that the NR is very near to a particular ER. Then there is no need to search for new ER and consequently the SESSION will be longer. Therefore, during the SESSION, Node Router will not check each incoming packet for signal strength. Thus battery drain-out may be prevented. Likewise, if the signal strength becomes volatile or decreasing gradually, it signifies that the Node Router is going away from concerned Edge Router. Then the SESSION will be shortened in order to initiate search for

neighboring Edge Routers. It is assumed that for that period, Node Router will remain in that PAN and the ER with which it is currently bound is the best choice for it. In Figure 5, a sequence diagram describes the approach.

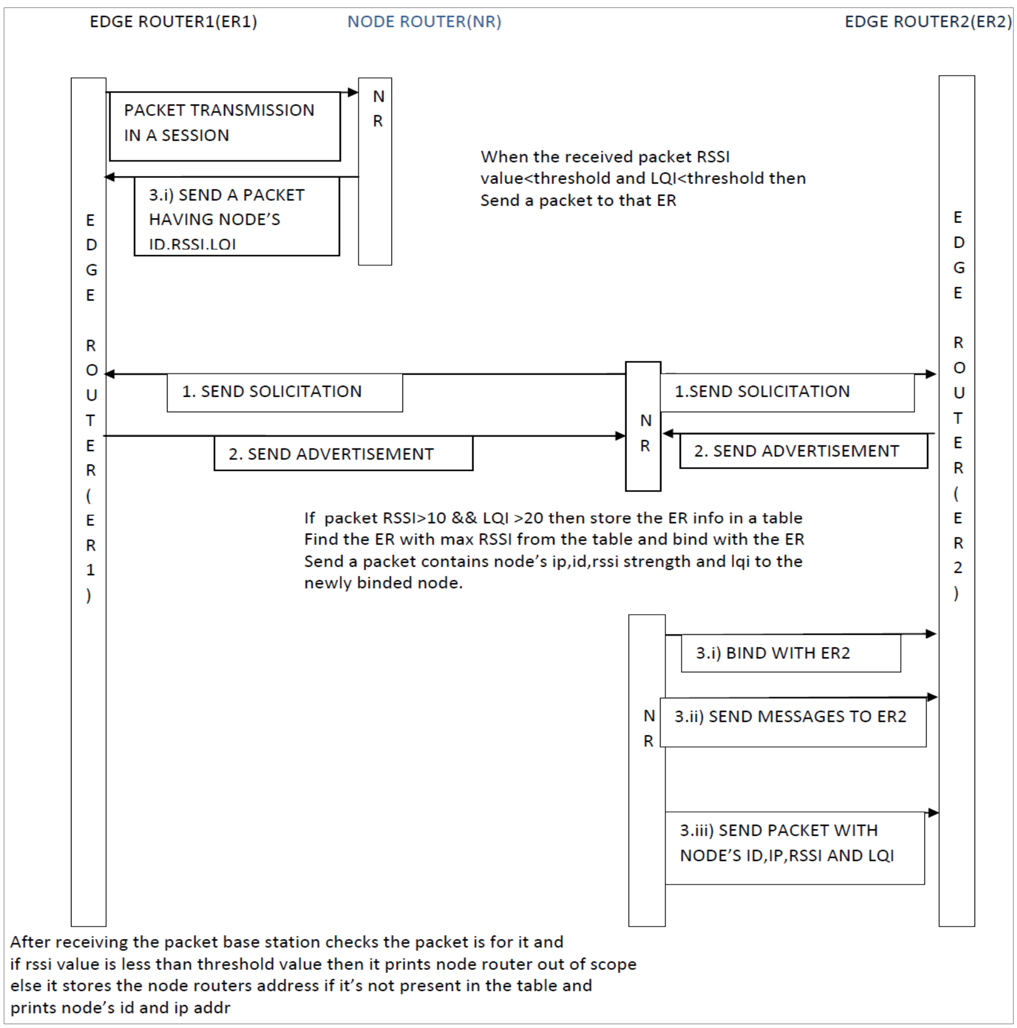

Figure 5 : Sequence diagram of message passing in Message Driven approach

D. Scheme for static Edge Routers

Here Edge Routers are static and they maintain a table for managing the Node Routers. The table is regularly updated to add a node in the PAN. Likewise, when a node leaves the PAN and sends 'release' message to the Edge Router, the table is updated and the corresponding entry is deleted.

Maximum number of nodes under every Edge Router is limited. It is aimed at minimizing the chances of greater node concentration in any particular PAN. Thus, node distribution among different PANs may be achieved. This technique may help in balancing loads, i.e. data traffic in the network. The pseudo-code of the scheme running on the Edge Routers is shown in Figure 6 and Figure 7 represents the route table of ER.

```
bind_node() {

// for selecting new Edge Router from moving node
if (recv( solicitation_msg, node.ip)==1)
// Edge Router successfully receives solicitation msg from moving node
          send(adv_msg,er.ip);
/* Edge Router sends adv_msg message in response to the solicitation message sent by moving node
*/

/* after receiving adv_msg moving node revert back to the Edge Router with binding_req */

if (recv(binding_req_msg, node.ip) ==1 && n_nodes < max_nodes )
          send(ack_msg, node.ip);
/* sends acceptance message when Edge Router finds maximum number of nodes is not reached */

else
          send(dec_msg, node.ip);
          //declines when Edge Router has maximum number of nodes

/* upon receipt of acceptance, moving node sends acknowledgement message to current Edge Router */

recv(ack_msg, node.ip);
// Edge Router receives the acknowledgement message from node upon successful binding

update_n_nodes();
//updates number of nodes

update_er_route_table();
//updates route table of the Edge Router
```

Figure 6 : Pseudo-code for mobility scheme of Edge Routers

node.ip	bind_time

Figure 7 : Route table structure for static Edge Routers

node.ip	IP of the moving node
er.ip	IP of the Edge Router
curr_er.ip	IP of the current Edge Router
new_er.ip	IP of the newly selected Edge Router
th_RSSI	threshold value of RSSI
th_LQI	threshold value of LQI
er_RSSI	RSSI of adv_msg received from an Edge Router
er_LQI	LQI of adv_msg received from an Edge Router
n_nodes	number of nodes in route table
max_nodes	maximum number of nodes an Edge Router can bind with
solicitation_msg	solicitation message
adv_msg	advertisement message
binding_req_msg	binding request message
ack_msg	acknowledgement message
release_msg	release message
dec_msg	decline message
bind_edge_router()	Function to bind Edge Router
bind_node()	Function to bind node
trigger_th()	Threshold trigger in moving node
send(msg, nodeIP)	Function to send message to node
recv(msg, nodeIP)	Function to receive message from node
broadcast(msg, ownIP)	Function to broadcast message to nodes
get_RSSI(msg)	Function to get RSSI
get_LQI(msg)	Function to get LQI
chk_IPv6_prefix(adv_msg, solicitation_msg)	Function to check IPv6 of received message
select_edge_router()	Function to select Edge Router
update_IPv6_prefix(new_er.ip)	Function to update IP of moving Edge Router
update_node_route_table();	Function to update route table of moving node
update_er_route_table();	Function to update route table of Edge Router
update_n_nodes();	Function to update number of nodes with Edge Router

Table 1: Variables, messages and functions used in pseudo-codes

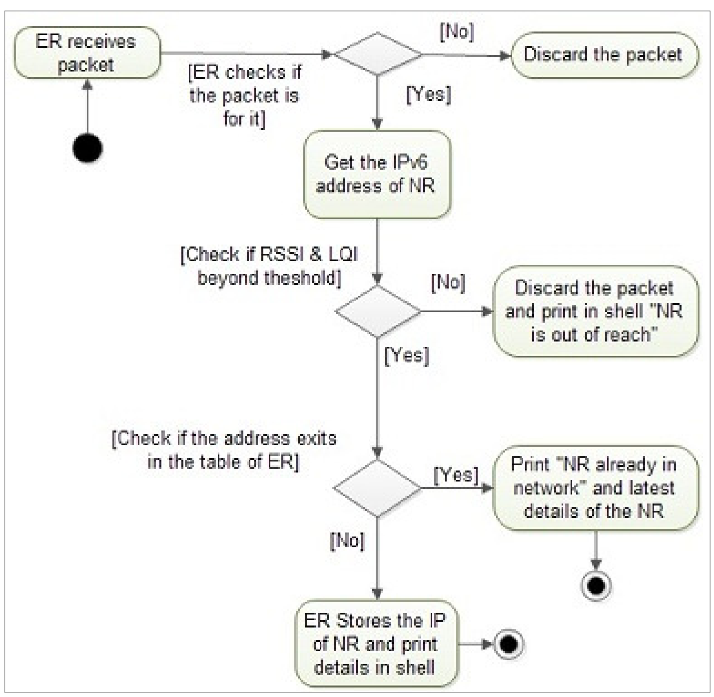

Figure 8 : Activity diagram for support of Edge Router

VIII. EXPERIMENTAL SETUP

In order to test applicability of the proposed mobility scheme, we have set up a test-bed for experimentation. The static Edge Routers are deployed in different locations and each of them remain connected with Ubuntu based PC. Wireshark [10] is installed on Ubuntu as packet sniffing tool. Edge Routers and nodes are installed with respective schemes which are discussed earlier.

A. Hardware

We have used the Crossbow's TelosB [12] mote as a hardware platform for our experiments. It is an open source platform designed to enable cutting-edge experimentation for the research community. It bundles all the essentials into a single platform, including USB programming capability, an IEEE 802.15.4 compliant radio chip (CC2420) with integrated antenna, a 8 MHz TI MSP430 micro-controller with 10kB RAM and 1MB external flash for data logging and programming and data collection via USB. Voltage requirement is at least 1.8 V, and it draws 1.8 mA in the active mode and 5.1 µA in the sleep mode.

B. Software

We have installed open-source TinyOS [13] Environment on Ubuntu 11. TinyOS 2.1.1 is used for this work. BLIP, the Berkeley Low-power IP stack [11], is an implementation of a number of IP-based protocols in TinyOS. This 6LoWPAN implementation is developed by the University of California, Berkeley. It was required to develop the appropriate code separately for both the schemes. Modifications were also done for some of the existing codes to enable the proposed scheme.

C. Testbed

Nodes are divided according to their assigned capability in the subnet. Connectivity to the Internet is provided via a small set of nodes which function as an interface between the subnet and Internet. These are called Edge Routers. Sensor nodes which route packets among themselves and to and from the Edge Routers are termed as Node Routers. IP is assigned to individual sensor nodes to ensure distinct identities. Using IP all the way to the sensor nodes provides transparent connectivity between the Internet and the subnet. We have created a test-bed for the study. The test-bed scenario is shown in Figure 9.

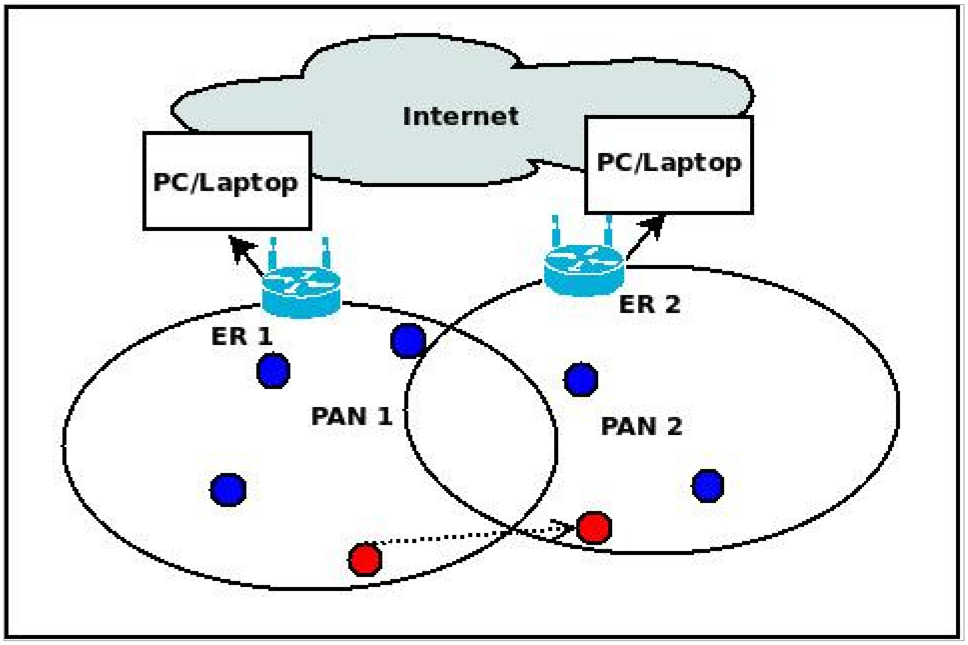

Figure 9 : Test-bed scenario

IX. AN EXAMPLE SCENARIO

This section provides the actual scenario what has come up due to the above implementation and provides the instances of system at different times. In Figure 10, the pictorial representation of the system is presented which considers that one node is moving among different PAN regions.

The identifiers t_i, t_{i+1}, ... represent node's position at different times when node is moving from ER 1 to ER 2. The corresponding tables are maintained by the Node Router and represent the entries at that time to select the best possible Edge Router, for example at t_{i+1} it is ER 1, at t_{i+2} it is ER 3 and at t_{i+4} it is ER 2. The blue entries specify the Edge Router's IP addresses to which the node binds. At those times each Edge Router also updates their table entries to maintain the list of Node Routers in their respective domains. Orange entries in the above figure show the positions of the mobile node at different instances.

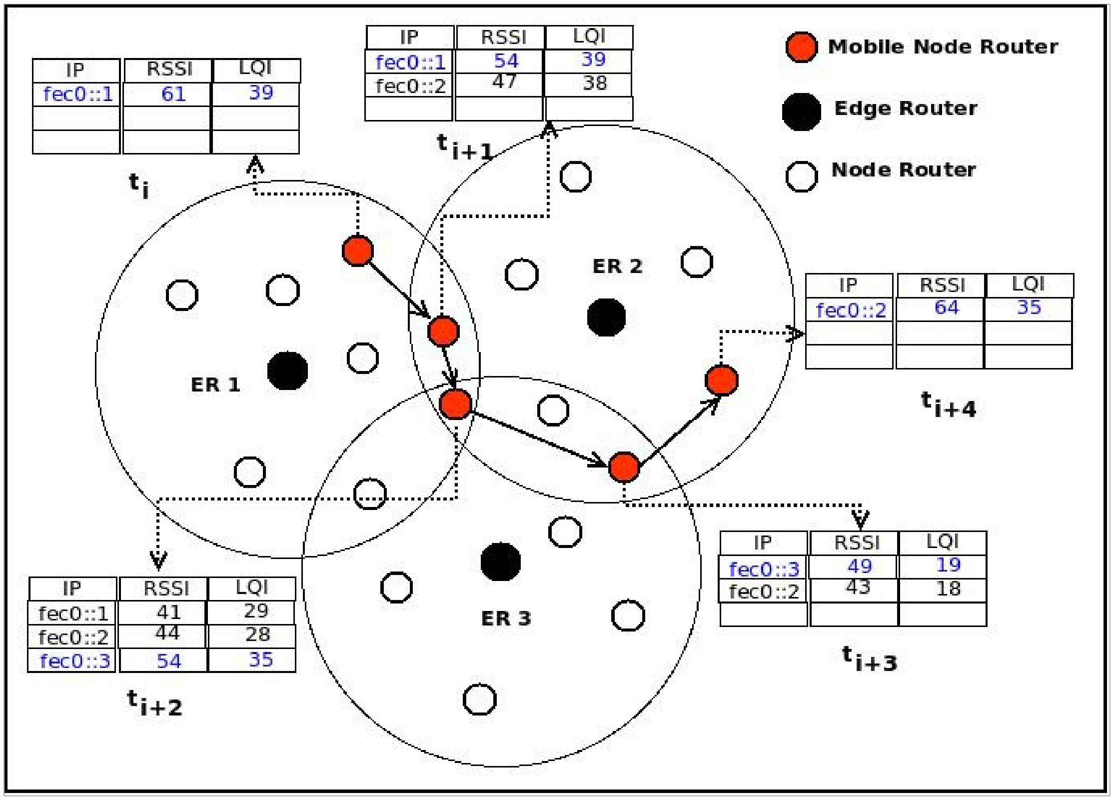

Figure 10 : Node movement in different inter PAN and corresponding table entry

Whenever a Node Router needs to change (i.e. at t_{i+2}) its Edge Router, it sends a message containing the measured RSSI and LQI to the connected Edge Router (ER 1). Then the ER checks from the message whether RSSI and LQI fall under certain threshold level. If so then it deletes the node information from the list and prints "node is unreachable" with IP of the node. Next (i.e. at t_{i+2}) NR sends to the newly connected ER (ER 2) its details like IP address, current RSSI and LQI. ER2 checks whether the node was previously included in its list; if it is not in the list then all the details are stored and ER2 prints "new node arrives" with its IP, otherwise it updates the current RSSI and LQI and prints "node is available" with the details.

Two approaches for implementing mobility of node routers help the Node Routers to initiate the search for new Edge Routers after checking corresponding signal strength. In timer driven approach, the checking is initiated when a certain time elapses and the Node Router checks signal strength continuously in case of message driven approach.

X. RESULT

For evaluation of the proposed schemes, few Edge Routers were deployed and each of the Edge Routers form individual PAN. A total of twelve nodes are kept under the PAN of Edge Routers. Among these nodes, few nodes are destined to be mobile in between these PANs. Wireshark is turned on from the very beginning on the PCs which are connected with the Edge Routers to monitor packets, time, rate and delays in transmission. ICMPv6 packets are sent from the Edge Router to the moving nodes with which they are binded. This was made through the ping6 application. A snapshot of the Wireshark tool is presented in Figure 11.

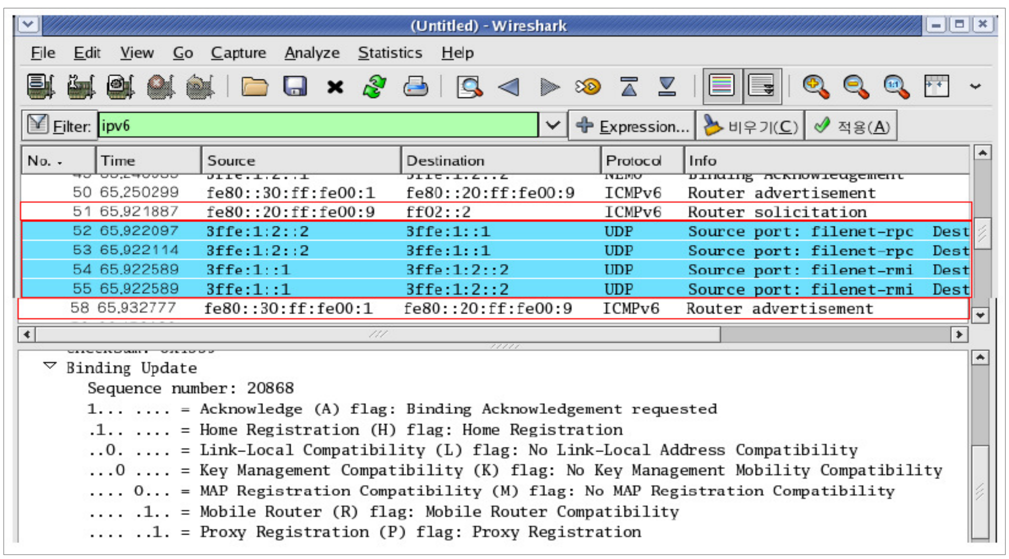

Figure 11 : Mobility visualization in Wireshark tool

A. Connectivity with the Edge Routers :

In this work, our aim is to ensure that the moving node keeps reverting back to the Edge Router even when the signal strength of communication link varies. To evaluate the efficacy in this regard, we have tested the round-trip time (RTT) and packet drop characteristic with respect to signal strength variation. Results of these experiments are shown in Figure 12 & 13 respectively. It is observed that round-trip time becomes minimal and percentage of packet drop turns to be negligible as the signal strength increases.

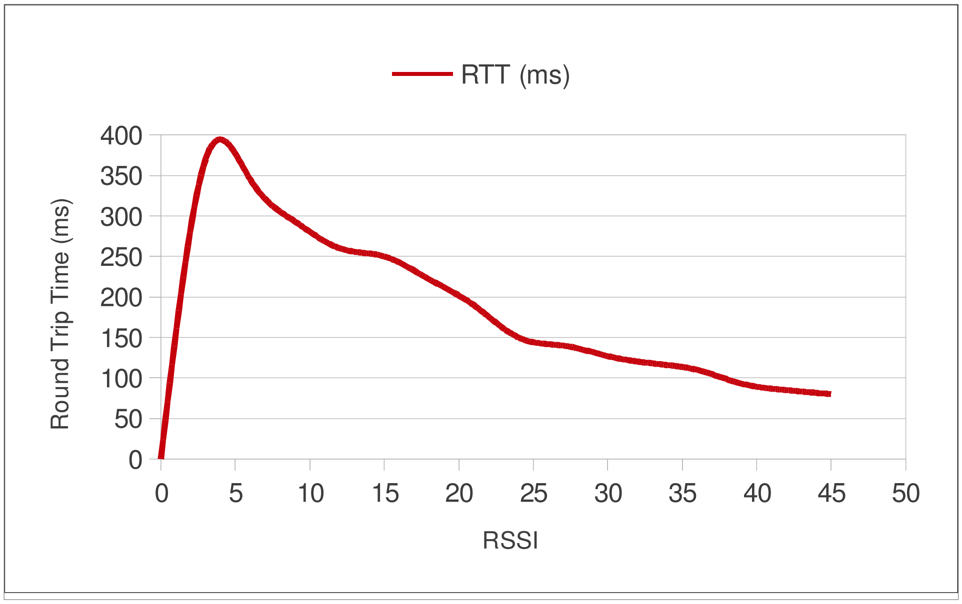

Figure 12 : RTT characteristic w.r.t. Signal strength

Figure 13 : Packet drop characteristic w.r.t. Signal strength

B. Edge Router selection by the mobile nodes :

First, we take a general approach to evaluate the efficiency of the proposed mobility schemes. At a certain point of time a moving node is taken far away from the corresponding Edge Router, so that the threshold value of signal strength is reached. Consequently, the moving node broadcasts solicitation message to the Edge Routers. This message is sniffed by the Wireshark. In response to the solicitation message, the Edge Routers send router advertisements to the moving node. In the mean time, the node moves closer to a new Edge Router. Node selects the Edge Router based on the signal strength and LQI value and sends binding request to the new Edge Router. Wireshark sniffs this message as well. When the Edge Router replies back with acceptance message, the node sends a message to current Edge Router for release. Immediately, current Edge Router releases the node and this message is also sniffed. Upon successful binding, the new Edge Router receives an acknowledgement and the Edge Router broadcasts a message regarding addition of the node.

We have performed the above process ten times each in following fifteen scenarios.

Scenario 1 : 3 Edge Routers are deployed with 1 mobile node.
Scenario 2 : 4 Edge Routers are deployed with 1 mobile node.
Scenario 3 : 5 Edge Routers are deployed with 1 mobile node.
Scenario 4 : 3 Edge Routers are deployed with 2 mobile nodes.
Scenario 5 : 4 Edge Routers are deployed with 2 mobile nodes.
Scenario 6 : 5 Edge Routers are deployed with 2 mobile nodes.
Scenario 7 : 3 Edge Routers are deployed with 3 mobile nodes.
Scenario 8 : 4 Edge Routers are deployed with 3 mobile nodes.
Scenario 9 : 5 Edge Routers are deployed with 3 mobile nodes.
Scenario 10 : 3 Edge Routers are deployed with 4 mobile nodes.
Scenario 11 : 4 Edge Routers are deployed with 4 mobile nodes.
Scenario 12 : 5 Edge Routers are deployed with 4 mobile nodes.
Scenario 13 : 3 Edge Routers are deployed with 5 mobile nodes.
Scenario 14 : 4 Edge Routers are deployed with 5 mobile nodes.
Scenario 15 : 5 Edge Routers are deployed with 5 mobile nodes.

Time taken in the total process is calculated using Wireshark tool. The calculation starts right from the time when moving node sends solicitation message to Edge Routers and ends with the receipt of acknowledgement at the new Edge Router. The calculated times from 10 iterations are averaged for each of the above six cases and the results are shown in Figure 14. It has been observed that the time for being connected to a new Edge Router increases with increasing number of mobile nodes. Presence of more mobile nodes implies more frequent changes in the network topology. Consequently, values of the key parameters change frequently leading to the increase in the said time. Also it is observed that involvement of more Edge Routers results in increase in the time for selection of Edge Routers.

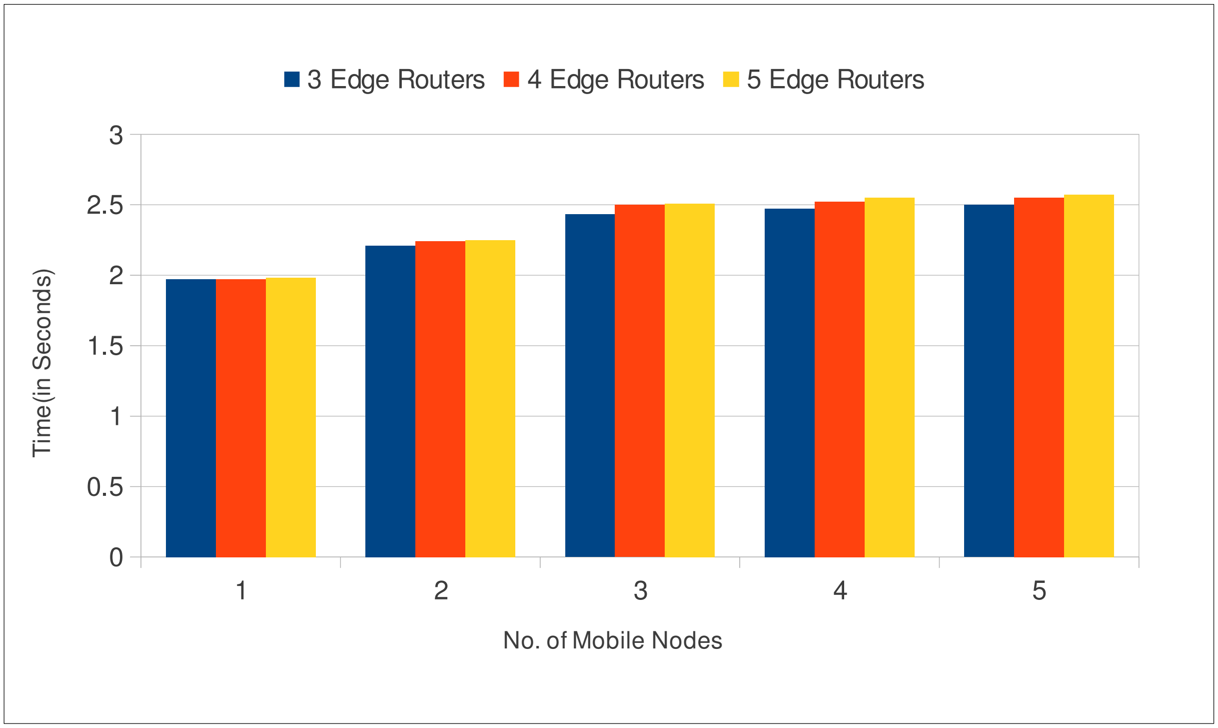

Figure 14 : Time taken for Edge Router selection

C. Evaluation of the mobility schemes :

Next, the two proposed approaches for implementing mobility of node routers are evaluated. Both approaches are evaluated within the experimental setup consisting of (1) 3 edge routers, (2) 4 Edge Routers and (3) 5 Edge Routers and different number of mobile nodes. Figure 15, 16 and 17 provide the data for remaining battery power in mobile node after certain number of hand-overs when 3, 4 and 5 Edge Routers are deployed respectively with 1 mobile node.

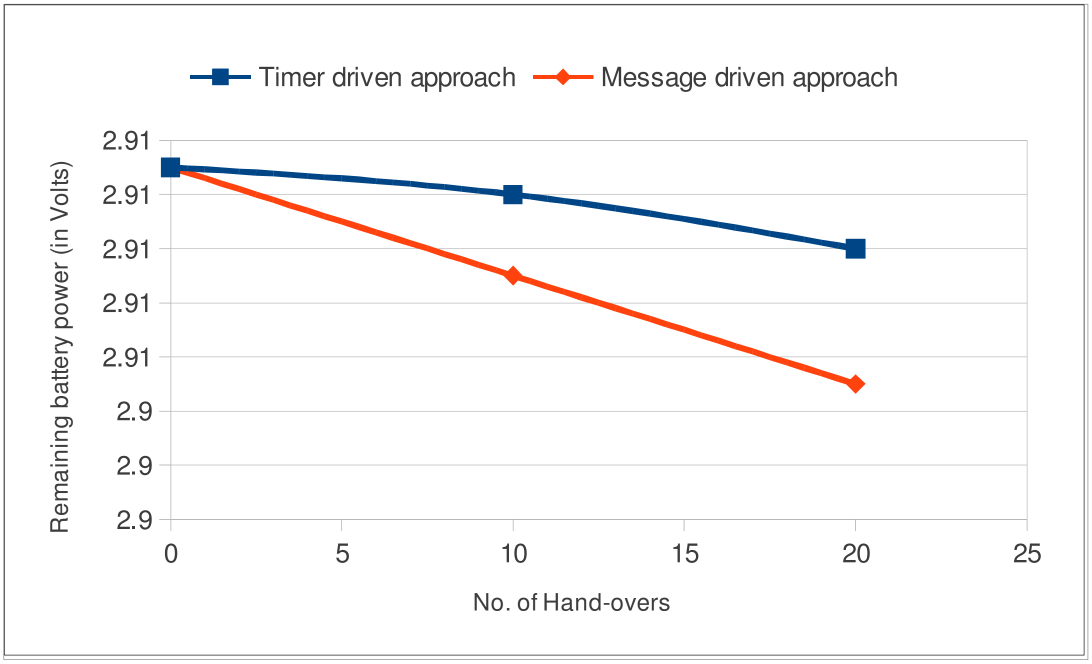

Figure 15 : Remaining battery power in mobile node with 3 Edge Routers

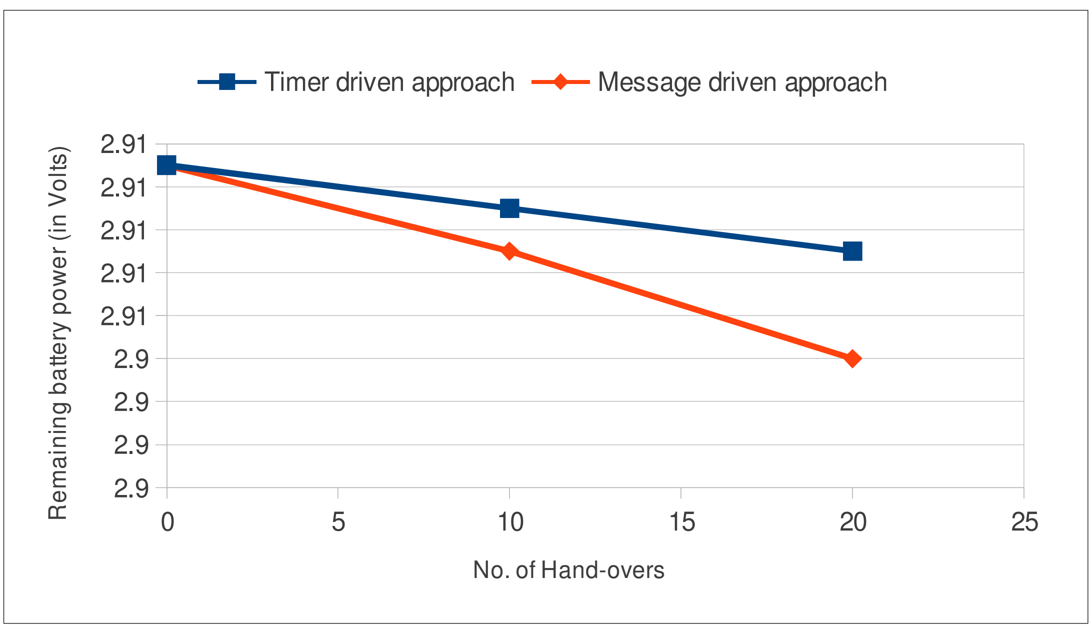

Figure 16: Remaining battery power in mobile node with 4 Edge Routers

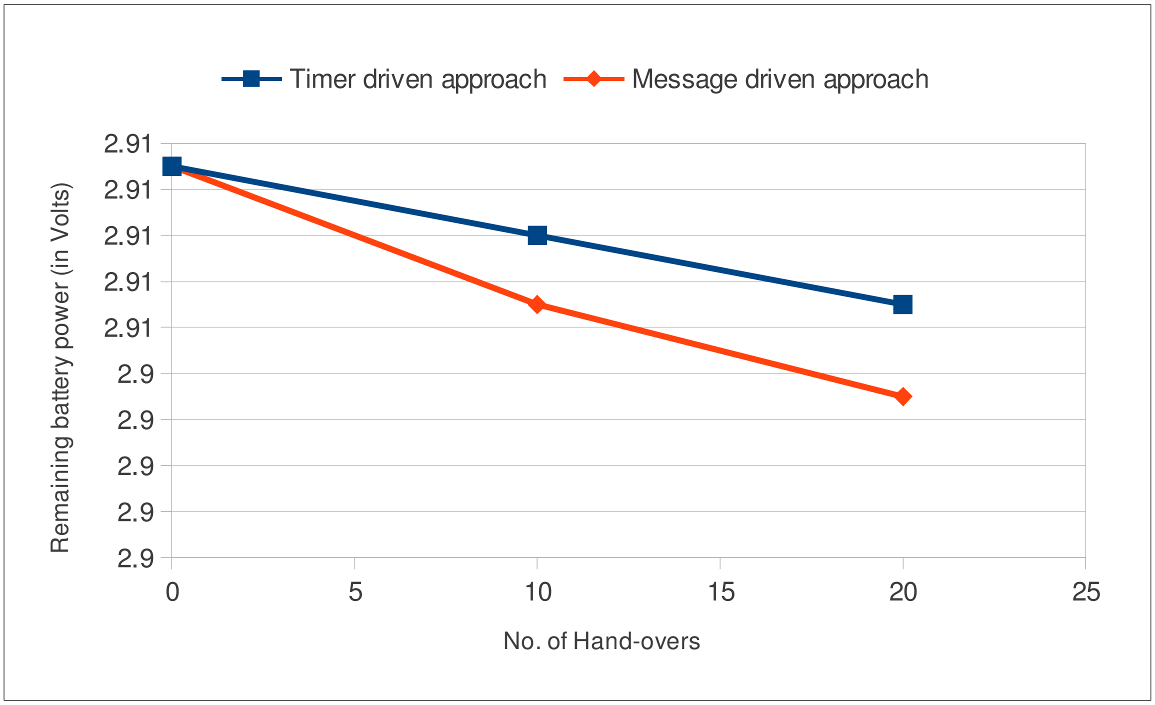

Figure 17: Remaining battery power in mobile node with 5 Edge Routers

Message driven approach involves checking of signal strength before sending solicitation to ER. Therefore, this checking incurs greater energy consumption in the concerned mobile node (although we have incorporated a 'SESSION' concept to tackle the issue). Therefore, performance of timer driven approach in terms of energy is better than the message driven approach.

On the other hand, message driven approach is more robust for tackling the mobility of a node. Instead of waiting till the timer is fired, here the node sends the solicitation message to ER whenever the threshold of signal strength is triggered.

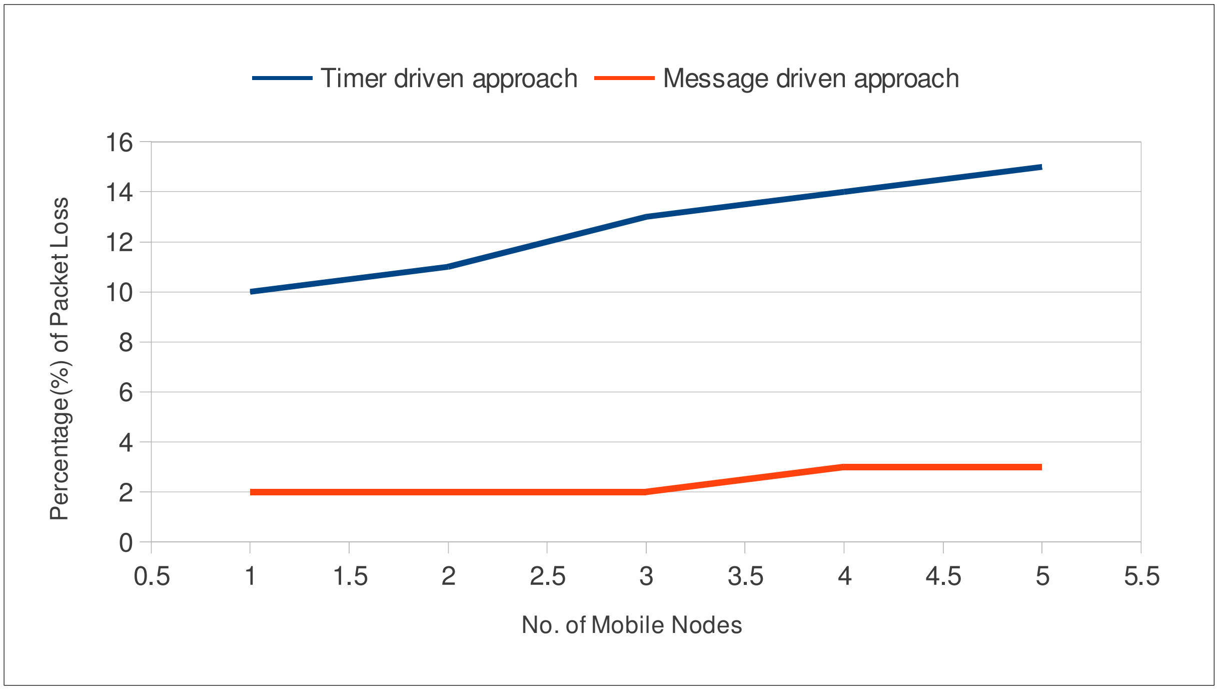

Figure 18 : Packet drop in mobile node when 3 Edge Routers

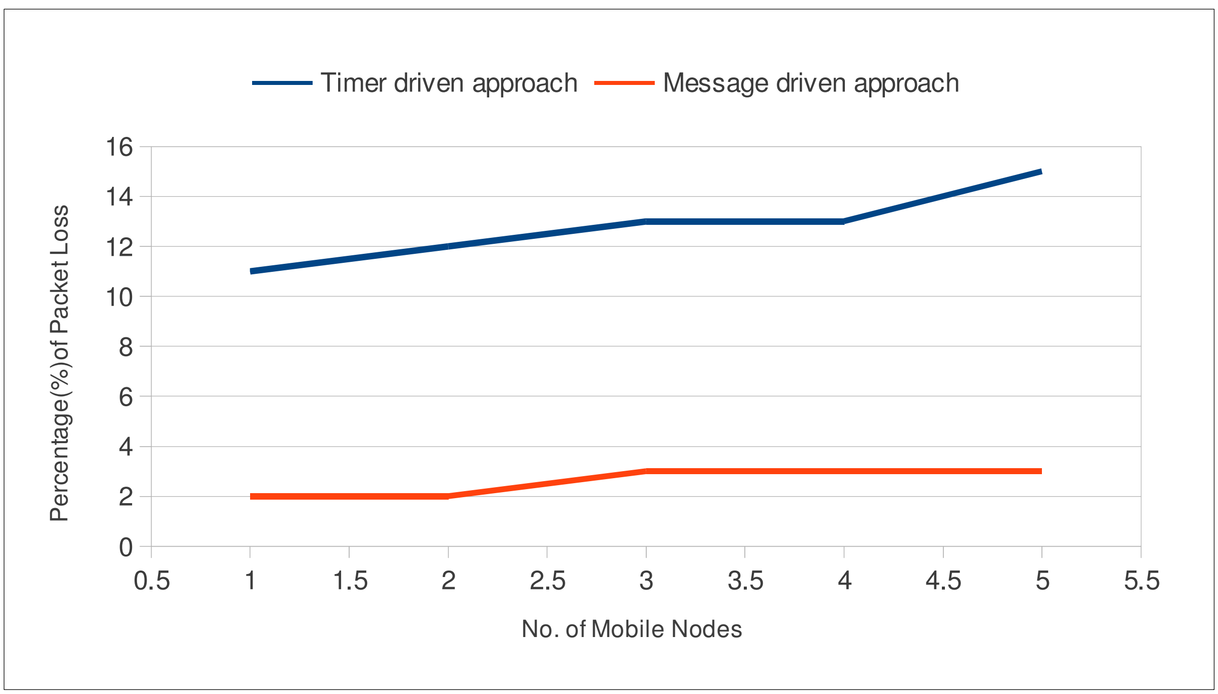

Figure 19: Packet drop in mobile node when 4 Edge Routers

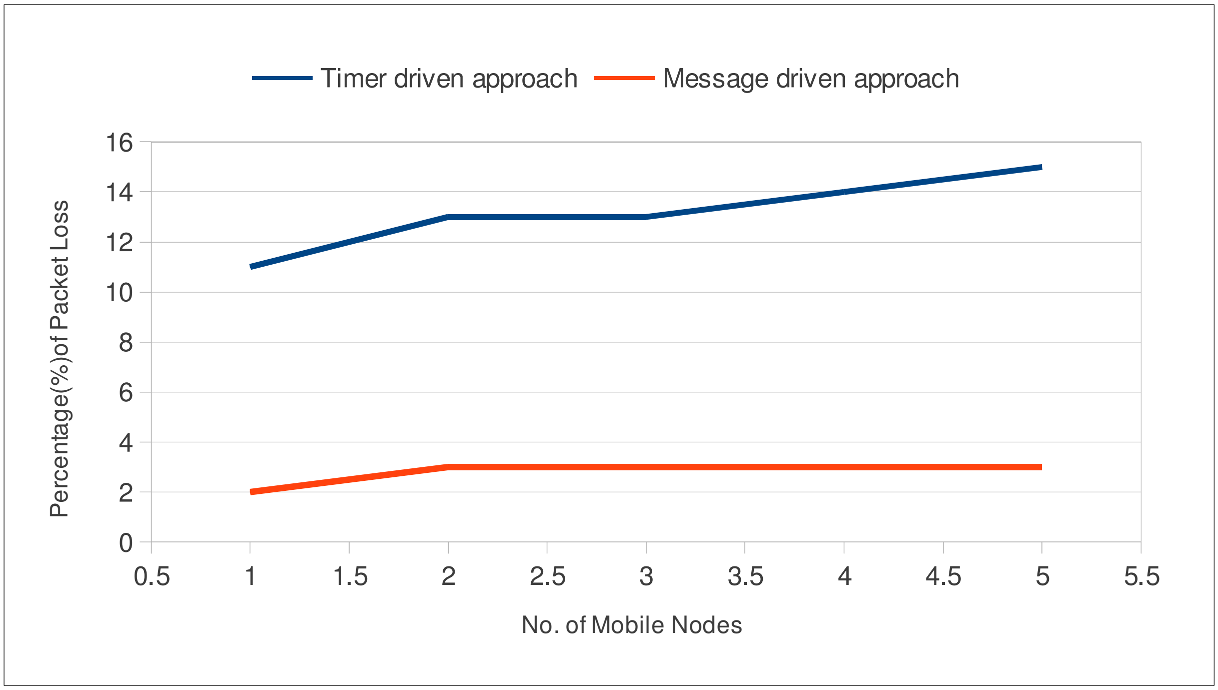

Figure 20: Packet drop in mobile node when 5 Edge Routers

Thus, for a highly mobile node, message driven approach ensures minimal packet drop as compared to timer driven approach. Even if the number of mobile nodes increases, message driven approach outperforms the timer driven approach in terms of packet drop. In Figure 18, 19 and 20, average percentages of packet drop are presented for both the implemented approaches when 3, 4 and 5 Edge Routers are deployed respectively.

Therefore, it may be concluded that these two approaches are applicable in two different scenarios. Timer driven approach is more suitable for applications where stay-period of a node under a PAN is predicable. Message driven approach is appropriate for applications where intensive mobility of node is involved. From the above study of the two approaches, it can also be observed that timer driven approach is more energy efficient.

XI. CONCLUSIONS

In this paper, we have discussed different mobility issues and scenarios in IP based wireless sensor network in a Sensor-grid infrastructure. The mobility management schemes are presented for the said infrastructure. These schemes are implemented for moving nodes and static Edge Routers. The schemes rely on the RSSI and LQI of the communication links for the selection of different PANs dynamically while on move. The mobility schemes are designed in such a way that communication link with Edge Router does not rupture because of mobility. The moving node selects a new Edge Router before connection with the current one dies out. On the other hand, the schemes with static Edge Routers ascertain balanced load in the network concerned. During mobility, knowledge of the current location of the moving node is crucial. Therefore, the schemes include a table at Edge Router to store the whereabouts of the moving nodes. This scheme will help the Sensor-grid infrastructure and all of it resources to connect, share sensory data even when the nodes are mobile. Though this implementation supports random mobility of the Node Routers, but it can be further improved so that it can provide support for some predictable movement as well.

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