Chapter 5

Mobility Management

5.1 Overview

In Chapter 2, challenges involving wireless sensors within the integrated sensor-cloud framework have been discussed. Among them, mobility management of sensor nodes for provisioning health-care services, is a significant challenge. In most health-care applications, continuous monitoring is required, but patient may happen to be mobile. It is assumed that wireless health sensors 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 from distant locations. A patient may walk around his own ward or he may be wheeled around different locations within the health-care center. Eventually, the sensors put up in a patient’s body 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. But precious health data should not be lost during mobility of patients. Therefore, mobility management of the health sensor nodes is very much required within this sensor-cloud framework.

In this chapter, the mobility issues in a 6LoWPAN environment are studied and a scheme is proposed to manage the mobility of sensor nodes based on received signal strength and link quality. Later, this scheme is modified with a proposal of intelligent mobility management where direction of node (patient) mobility is taken under consideration along with aforesaid two parameters. Still there exists problem when 6LoWPAN coverage is not available. In the era of smart city, various access technologies (UMTS, WiFi, WiMax etc.) are in abundance [60]. So, a solution is proposed to handle the mobility across heterogeneous access technologies.
5.2 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. Few schemes are evaluated on the basis of simulation results. In [61], inter-pan mobility support for 6LoWPAN is discussed and a simulation-based study 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 [62]. 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 [63], 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 [61–63], in this work a scheme for mobility management in 6LoWPAN is implemented in TinyOS and run onto the wireless sensor nodes.

Remainder of this chapter is organized as follows. Section 5.3 highlights issues pertaining to design of mobility schemes for 6LoWPAN devices and Section 5.4 presents different mobility scenarios. A mobility management scheme is proposed in Section 5.5. This schemes is improved with consideration of direction of node mobility in Section 5.6. Next a vertical handover scheme is presented in Section 5.7. This chapter is summarized in Section 5.8.

5.3 Mobility Scheme Design Issues

6LoWPANs have unique properties which enable tiny devices with little memory and power, to be connected to IP network. However, new challenges arise when the nodes become mobile. It is crucial to reduce the additional mobility related signalling overhead or to possibly avoid it altogether. 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. The fundamental goals for mobility support in 6LoWPANs are listed on IETF draft [64]:

1. Mobile 6LoWPAN nodes must be addressable by any corresponding node, independent of the current whereabouts. Global addressing should be supported. It should satisfy the 6LoWPAN basic protocol.
2. Mobility related signaling for nodes should be reduced, as much as possible.

3. Fast handover detection should be supported.

4. Mobile 6LoWPAN devices should be able to change their location while being in state of hibernation.

5. Fragmentation must be avoided for signaling messages.

6. Star topology as well as mesh topology must be supported.

5.4 Mobility Scenarios in 6LoWPAN

In 6LoWPAN each edge router forms a PAN with few other nodes and the edge router acts as sink node of the concerned PAN. Here other nodes are called node routers. In health-care applications, patient node is the node router. In this discussion, it is assumed that edge routers are static. So, network mobility is beyond the scope of this thesis. 6LoWPAN uses flat address space which means that all nodes within one certain subnet share the same IPv6 prefix [23]. Two different mobility scenarios may occur for the node routers.

**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 as IPv6 prefix remains same for the moving node. In this scenario, the moving node updates its current location while keeping the radio link with concerned edge router alive.

**Inter-pan mobility**

If a node moves from one PAN to another PAN, it is 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. For this reason, it is termed as ‘macro’ mobility as well.
5.5 Proposed Scheme

In this section, a mobility scheme for 6LoWPAN enabled nodes is proposed. The scheme is described in two subsections for the moving nodes (i.e. node routers) and the static edge routers respectively. Before that, two important metrics are discussed which will be referred in the mobility scheme later on.

Received Signal Strength Indicator

Received Signal Strength Indicator or RSSI is a 5-bit value indicating the received power in the selected communication channel, in steps of 3 dB. The current RSSI value is stored to the PHY_RSSI register of the transceiver [65]. Range of the value is 0 - 28. An RSSI value of 0 indicates a radio frequency (RF) input power of $<-91$ dBm. The RF input power ($P$) can be calculated as follows [65]:

\[
P = \text{RSSI}_{VAL} + \text{RSSI}_{OFFSET}[\text{dBm}]
\]  

where the \text{RSSI}_{OFFSET} is approximately -45 [65]. If a value of -20 is read from the RSSI register, the RF input power is approximately -65 dBm.

Link Quality Indicator

The IEEE 802.15.4 standard defines the Link Quality Indicator or LQI measurement as a characterization of the strength and/or quality of a received packet. 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 [65]:

\[ LQI = (CORR - a) \times b \] (5.2)

where \( a \) and \( b \) are found empirically based on packet error rate (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.

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 [65].

### 5.5.1 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 values are reached, the moving node initiates a search for other prospective edge routers (ER) in order to avoid isolation from the network. The pseudo-code in Figure 5.3 describes the scheme for the moving nodes and Figure 5.4 represents the route table which is maintained by moving nodes.

While moving, node router (NR) checks the RSSI of the link with edge router (ER) concerned. The scheme uses two approaches:

- Timer driven
- Message driven

#### 5.5.1.1 Timer driven approach

This approach is based on a timer event which is fired periodically. Signal strength of ER is checked after certain interval (\textit{TIME\_PERIOD}). The challenge is to define the
Table 5.1: Variables, messages and functions used in pseudo-codes

<table>
<thead>
<tr>
<th>Variable/Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>node.ip</td>
<td>IP of the moving node</td>
</tr>
<tr>
<td>er.ip</td>
<td>IP of the Edge Router</td>
</tr>
<tr>
<td>curr.er.ip</td>
<td>IP of the current Edge Router</td>
</tr>
<tr>
<td>new.er.ip</td>
<td>IP of the newly selected Edge Router</td>
</tr>
<tr>
<td>th_RSSI</td>
<td>threshold value of RSSI</td>
</tr>
<tr>
<td>th_LQI</td>
<td>threshold value of LQI</td>
</tr>
<tr>
<td>er_RSSI</td>
<td>RSSI of adv_msg received from an Edge Router</td>
</tr>
<tr>
<td>er_LQI</td>
<td>LQI of adv_msg received from an Edge Router</td>
</tr>
<tr>
<td>n_nodes</td>
<td>number of nodes in route table</td>
</tr>
<tr>
<td>max_nodes</td>
<td>maximum number of nodes an Edge Router can bind with</td>
</tr>
<tr>
<td>solicitation_msg</td>
<td>solicitation message</td>
</tr>
<tr>
<td>adv_msg</td>
<td>advertisement message</td>
</tr>
<tr>
<td>binding_req_msg</td>
<td>binding request message</td>
</tr>
<tr>
<td>ack_msg</td>
<td>acknowledgement message</td>
</tr>
<tr>
<td>release_msg</td>
<td>release message</td>
</tr>
<tr>
<td>dec_msg</td>
<td>decline message</td>
</tr>
<tr>
<td>bind_edge_router()</td>
<td>Function to bind Edge Router</td>
</tr>
<tr>
<td>bind_node()</td>
<td>Function to bind node</td>
</tr>
<tr>
<td>trigger_th()</td>
<td>Threshold trigger in moving node</td>
</tr>
<tr>
<td>send(msg, nodeIP)</td>
<td>Function to send message to node</td>
</tr>
<tr>
<td>recv(msg, nodeIP)</td>
<td>Function to receive message from node</td>
</tr>
<tr>
<td>broadcast(msg, ownIP)</td>
<td>Function to broadcast message to nodes</td>
</tr>
<tr>
<td>get_RSSI(msg)</td>
<td>Function to get RSSI</td>
</tr>
<tr>
<td>get_LQI(msg)</td>
<td>Function to get LQI</td>
</tr>
<tr>
<td>chk_IPV6_prefix(adv_msg, solicitation_msg)</td>
<td>Function to check IPv6 of received message</td>
</tr>
<tr>
<td>select_edge_router()</td>
<td>Function to select Edge Router</td>
</tr>
<tr>
<td>update_IPV6_prefix(new_er.ip)</td>
<td>Function to update IP of moving Edge Router</td>
</tr>
<tr>
<td>update_node_route_table()</td>
<td>Function to update route table of moving node</td>
</tr>
<tr>
<td>update_er_route_table();</td>
<td>Function to update route table of Edge Router</td>
</tr>
<tr>
<td>update_n_nodes();</td>
<td>Function to update number of nodes with Edge Router</td>
</tr>
</tbody>
</table>

**TIME_PERIOD.** It should depend on how frequently a node changes its position. If a mobile Node Router changes its position frequently, **TIME_PERIOD** should be less because Node Router may go beyond the range 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.

- 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 and LQI and stores details of ER in a table. For experimentation, threshold values of RSSI and LQI are set to 10 and 20 respectively. These values are set in accordance with the datasheet of the transceiver.
- NR searches the table for ER with highest RSSI and sends binding request along with its IP. Also, NR sends a release request to current ER.
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 );
// moving node obtain RSSI of adv_msg
er_RSSI = get_RSSI ( adv_msg );
// moving node obtain LQI of adv_msg
if ( th_RSSI < er_RSSI && th_LQI < er_LQI )
    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 */
    new_er = select_edge_router ();
// select_edge_router () returns the ip of the selected Edge Router
/* moving node now selects a new 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 );
/* moving node acknowledges newly selected Edge Router upon successful binding */
} // end of while loop
}
/* Figure 5.3: Pseudo-code for mobility scheme of nodes */

• After receiving the request, new ER binds the node with it and stores details in a
table.

• ER prints on screen the IP address of newly associated NR.

Figure 5.5 presents a sequence diagram for the above mentioned steps.
5.5.1.2 Message driven approach

This approach is based on the signal strength of the received message from the 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 needs 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 \textit{SESSION}. Here \textit{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 \textit{SESSION} may depend on certain heuristic. The length of the \textit{SESSION} is defined as a function of the three previous values of signal strength (RSSI) from current edge router.

\[
\text{SESSION}_i = f(RSSI_i, RSSI_{i-1}, RSSI_{i-2})
\]

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 the concerned Edge Router. Then the **SESSION** will be shortened in order to initiate search for neighboring Edge Routers. It is assumed that during the **SESSION**, Node Router will remain in that PAN and the ER with which it is currently bound is the best choice for it.

In Figure 5.6, a sequence diagram describes the approach. The node NR communicates with ER1 during a **SESSION** and moves towards ER2. Meanwhile, threshold values of RSSI and LQI are triggered. So, NR sends solicitation message in search of edge routers. Edge routers reply back with advertisement messages. NR considers only those advertisements whose RSSI, LQI value is greater than threshold. Then, ER2 is selected as it gives greater RSSI than ER1. Control messages are exchanged between NR and ER2.

![Sequence diagram of message passing in Message Driven approach](image)

**Figure 5.6:** Sequence diagram of message passing in Message Driven approach
5.5.2 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 \texttt{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 5.7 and Figure 5.8 represents the route table of ER. In Figure 5.9, activity of Edge Router is shown.

```c
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
}
```

\textbf{Figure 5.7:} Pseudo-code for mobility scheme of Edge Routers

\textbf{Figure 5.8:} Route table structure for static Edge Routers
5.5.3 Experiments and Result

As described in 3.6.3, the deployed testbed in SMCC building has been used. For evaluation of the proposed mobility scheme, 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.

In the following subsections, different sets of experiments are described and the results are shown.

5.5.3.1 Connectivity with the Edge Routers

Aim of this work 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, test has been performed to measure the round-trip time (RTT) and packet drop characteristic with respect to signal strength variation. Results of these experiments are shown in Figure 5.10 & 5.11 respectively. It is observed that, as expected, round-trip time becomes minimal and percentage of packet drop turns to be negligible as the signal strength increases.
5.5.3.2 Edge Router Selection by the Mobile Nodes

First, a general approach is taken 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 the 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 broadcasts a message regarding addition of the node. Above process is performed ten times in each of the 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 15 scenarios and the results are shown in Figure 5.12. 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 of the time for selection of Edge Routers.

![Figure 5.12: Time taken for Edge Router selection](image)

5.5.3.3 Evaluation of Two Approaches in Mobility Scheme

Next, the two proposed approaches for implementing mobility of node routers are evaluated. Both approaches are evaluated within the experimental setup consisting of:
(i) 3 edge routers, (ii) 4 Edge Routers and (iii) 5 Edge Routers with different number of mobile nodes.

Figure 5.13, 5.14 and 5.15 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 5.13:** Remaining battery power in mobile node with 3 Edge Routers

**Figure 5.14:** Remaining battery power in mobile node with 4 Edge Routers

**Figure 5.15:** Remaining battery power in mobile node with 5 Edge Routers
Message driven approach involves checking of signal strength before sending solicitation message to ER. Therefore, this checking incurs greater energy consumption in the concerned mobile node although a SESSION was incorporated 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. Figure 5.16, 5.17 and 5.18 show the data for packet loss in mobile node after certain number of hand-overs when 3, 4 and 5 Edge Routers are deployed respectively with 1-5 mobile nodes.

Here, 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. 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.

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
5.6 Mobility with Direction

When the wireless sensor nodes are in the vicinity of edge routers, it is possible to communicate among themselves and nodes move around within LoWPAN coverage area, i.e. typically within the hospital premises or home. Thus, inter-pan mobility happens with the help of horizontal handover mechanism. During implementation [74], instances are observed when the mobile sensor node performs handover with the edge router in one direction (due to higher signal strength and/or good link quality) but actually moves towards opposite direction. Thus the sensor node is required to perform handover along the direction of its movement. So, mobility of health sensors should be intelligent enough to do the handover in correct direction to keep handover latency lower and to prevent battery exhaustion due to unnecessary signalling cost. In this section, a proposal is made to improve the mobility scheme mentioned in the previous section. In Figure 5.19, a situation for probable handover is shown where the moving sensor node is required to make the decision for handover by selecting one among the three available edge routers which are located at different directions. Here, the knowledge related to the direction of the node’s movement held to take the appropriate decision.
5.6.1 Direction

Direction of the node movement is another metric, which is considered along with previous two metrics, namely RSSI and LQI, in this improved mobility scheme. The direction may be determined through localization technique, where a series of locations of the concerned node shows its direction of movement. There are various localization techniques, such as trilateration/triangulation, Angle of Arrival (AoA) and Time Difference of Arrival (ToA / TDoA). But for ease of implementation, AoA technique is used for detection of direction of movement of the node. It is readily available at the nodes.

AoA is defined as the angle between the propagation direction of an incident signal and some reference direction. Usually, the AoA is calculated in clockwise direction from the North and represented in degrees. It is said to be absolute when calculated with respect to the North. Otherwise, AoA is relative when calculated with some other reference direction.

In Figure 5.20, the health sensor node M is moving in $\overrightarrow{KL}$ direction when it finds two edge router A and B. So, $\overrightarrow{KL}$ is reference direction here. The incident signals from B and A create $\angle LMB$ and $\angle LMA$ angles respectively with the reference direction. Henceforth, these are mentioned as angles of arrival, $\text{AoA}_A = \theta_2$ and $\text{AoA}_B = \theta_1$. These two measures of angles will be absolute if $\Delta\theta$ is added.

$$\text{Absolute AoA}_A = \theta_2 + \Delta\theta$$  \hspace{1cm} (5.4)
Absolute AoA 

\[ \theta_B = \theta_1 + \Delta \theta \]  

(5.5)

As the work is not aligned with localization, absolute angle of arrival is not necessary and calculation is cumbersome in the absence of GPS data. Since, patient moves with the health sensor node inside a building, GPS is not functional. But \( \theta_1 \) and \( \theta_2 \) suffice the purpose and are readily available. So, angle of arrival with reference to the direction of node mobility, is taken under consideration here.

In the next subsection, an intelligent mobility management scheme is presented considering mobility direction along with signal strength and link quality.

### 5.6.2 Proposed Intelligent Mobility Management

In [67], it is shown that “the amount of energy spent for sending a single bit of data is approximately same with that of executing 800 instructions in a sensor node”. So, in order to minimize unnecessary signalling cost, a fuzzy assisted intelligent mobility management scheme is proposed to tackle the horizontal handover decision problem when a patient with health sensors is moving around within 6LoWPAN.

A fuzzy assisted solution is proposed here because it is much closer to the way of human thought process. Also, it is intuitive and easy to use as compared to other classification algorithms based on probability theory. Here, it helps to solve the uncertainty over appropriate handover decision.

A fuzzy inference system (FIS) (as discussed in Section 4.6.3.1) is designed to make the handover decision.

#### Fuzzification

As discussed earlier, the crisp input variables \( x \in X \) (X is the set of possible input variables) are converted into fuzzy linguistic variables by Fuzzifier with the help of membership functions which are defined in the Knowledge Base. Linguistic variables are defined by Zadeh as “variables whose values are not numbers but words or sentences in a natural or artificial language” [57].

Instead of putting some threshold values for a good link, here signal strength (RSSI), link quality (LQI) and direction are considered as crisp input to the fuzzifier. Then, fuzzifier creates respective fuzzy sets. Here fuzzy sets look like: weak/ average/ strong values for RSSI, low/ medium/ high values for LQI and less/ medium/ high values for direction.
Fuzzy Inference Engine

Decision making is done at the Fuzzy Inference Engine with the help of rule-base. The rule-base is composed of some pre-defined rules i.e. set of linguistic statements in the form of “IF premise, THEN consequent”. Then the decision is sent as a fuzzy set to defuzzifier.

De-fuzzification

The conversion from fuzzy set to crisp set is called defuzzification. Here, the fuzzy set contains data about the decision which is provided to constitute an event. This event is nothing but selection and binding with appropriate edge router along the trajectory of the mobile health sensor node. Thus, the health sensor nodes make smart mobility decision eliminating undesired signalling costs.

In practice, defuzzification is done using centroid method.

\[ z^* = \frac{\int \mu_A(z) \cdot z \, dz}{\int \mu_A(z) \, dz} \]  \hspace{1cm} (5.6)

where, \( \mu_A(z) \) is the membership function of set A.

5.6.3 Implementation

In order to test applicability of the proposed intelligent mobility scheme, a test-bed [59] is used for experimentation. More number of edge routers within a small area are deployed to create an ideal situation for frequent handovers and inter-pan mobility. For this work, five static Edge Routers are deployed at different strategic locations.

As hardware platform, Crossbow’s TelosB is used for experiments. Open-source TinyOS 2.1.1 [27] is installed on Ubuntu. BLIP, the Berkeley Low-power IP stack [28], is an implementation of a number of IP-based protocols in TinyOS. This 6LoWPAN implementation is used along with required modifications to enable the proposed intelligent mobility scheme. The direction (AoA) along with RSSI and LQI is fetched through respective functions of TinyOS.

In Figure 5.21, membership functions for the received signal strength are shown as weak, average and strong in the range of -100 to 0 dBm. Membership functions for the link quality are described in Figure 5.22 as low, medium, high in the range of 0 to 255 after consulting datasheet[65].
Figure 5.21: Input membership function of Signal strength

Figure 5.22: Input membership function of Link quality

Figure 5.23: Input membership function of Direction

Figure 5.23 presents membership functions for direction in terms of angle of arrival as shown in Figure 5.20. Here, the membership functions are shown in the range of 0 to 180 degrees. Same membership functions are applied for the range of 0 to -180 degrees. AoA in the range of 0 to 50 degrees is described as highly directed, i.e. towards the movement direction of the node. Other membership functions are medium directed and less directed. Medium directed denotes that the position of edge router is almost perpendicular to the trajectory of the mobile node. Less directed describes the position of edge router in opposite direction of the node mobility.
Membership functions for output are shown in Figure 6.7. Decisions are described as very low, low, medium, high, very high membership functions. These functions help to choose among the available edge routers before performing the handover. Handover is performed with edge router with highest membership function.

![Output membership function](image)

**Figure 5.24:** Output membership function

A set of rules are defined in the rule base as shown in Figure 5.25. The rules are set in such a way that fuzzy inference engine may decide which edge router is best to bind with. To describe how the rules have been constituted, first rule in Figure 5.25 is considered. *If signal strength is weak and link quality is low and direction is less directed then output is very low.* This means any edge router which meets conditions of rule 1, will not be selected for handover when better match is available.

A better match can be found from rule 6. *If signal strength is strong and link quality is high and direction is highly directed then output is very high.* Chances of getting selected as handover candidate is very high for an edge router which satisfies the rule 6.

Figures 5.26, 5.27 show control surface of output based on the input parameters. In Figure 5.26, it is shown how the output varies with different values of signal strength and direction. It can be observed that output is increased to very high/high for a edge router which is situated towards the trajectory of the node and has strong signal strength. But the output has gone down to very low for a edge router in opposite direction and weak signal strength.

In Figure 5.27, it is shown how the output varies with different values of link quality and direction. Here, the above discussion may be reiterated with respect to link quality and direction.
5.6.4 Results

As mentioned in Section 5.6.3, the proposed fuzzy assisted intelligent mobility is implemented on the real testbed. Also, a normal mobility scheme is implemented on the same testbed with identical configuration. As mentioned in Section 5.5, the normal method uses a threshold technique for signal strength and link quality, but lacks any provision for direction.
In both methods, moving node broadcasts solicitation messages in search of Edge Routers. Nearby Edge Routers send router advertisements in response to the solicitation messages. Then the mobile node decides upon candidate Edge Router and sends binding request. Consequently, concerned Edge Router replies back with acceptance message and mobile node sends release message to the current Edge Router. Immediately, current Edge Router releases the node. Upon successful binding, the new Edge Router receives an acknowledgement and the Edge Router broadcasts a message regarding addition of the node.

Time taken in the total process is measured using Wireshark tool. The measurement 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. For experimentation, 50 hand-overs are performed for each of the methods. The calculated times from 50 hand-overs are averaged and it is shown in Figure 5.28.

It has been observed that the time for being connected to a new Edge Router is less in the Fuzzy-based method. In case of normal method, presence of more Edge Routers implies more computation with individual network parameters. Also, more signalling overhead for decision making is expected in the absence of mobility direction. So, normal method requires more time.

Same reasons are accountable for more energy dissipation in the normal method than the proposed method. The residual battery power of the mobile node is noted after each 10 hand-overs till the fiftieth hand-over. From Figure 5.29, it may be observed that with more number of hand-overs, battery depletion is quicker in normal method.
Another performance metric, packet drop provides marginal improvement over the normal method as shown in Table 5.2.

Table 5.2: Packet Drop

<table>
<thead>
<tr>
<th>Normal Method without Mobility Direction consideration</th>
<th>2-10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed Method considering Mobility Direction</td>
<td>0-2%</td>
</tr>
</tbody>
</table>

Performance evaluation of fuzzy inference system

Although the proposed fuzzy based method outperforms the normal method, a performance study has been done of the proposed fuzzy inference system. In order to compute the performance of a fuzzy system, decisions made by it have to be counted. In machine learning, decisions are of four types: true positive (TP), true negative (TN), false positive (FP) and false negative (FN) [68]. There are three standard measures exist for performance evaluation [69]. Those are, namely,

\[
Precision = \frac{TP}{TP + FP} \quad (5.7)
\]

\[
Sensitivity = \frac{TP}{TP + FN} \quad (5.8)
\]

\[
Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (5.9)
\]

Based on the decisions made during the 50 hand-overs, Equations 5.7, 5.8 and 5.9 provide precision 97.56 %, sensitivity 95.238% and accuracy 94%.
In the proposed fuzzy inference system, pre-defined rules are used. In the rule-base, attributes (i.e. RSSI, LQI, direction) are assigned with values initially which will not change over time. Thus, it is a non-adaptive system. In contrast, in adaptive system the initial assigned values of the rules are updated every time. Therefore, no time has been required for rule generation or evaluation in the proposed fuzzy inference system.

The sensor nodes provide some discrete values for the attributes (i.e. RSSI, LQI, direction). Thus, the proposed system dealt with discrete signals only.

Triangular function is a simple, yet effective due to its linear nature. In the proposed fuzzy inference system, linear membership variation has been preferred so that only one value could have a complete belongingness to a particular state (viz. low, medium, high). Therefore, triangular function is used here.

As triangular functions have been used during fuzzification, $\mu_A(z)$ of Equation 5.6 becomes linear in nature. Therefore, simple linear transformation is required during defuzzification. It needs negligible time. Thus, it does not cause any effective delay in the system. Consequently, computation time (as shown in Figure 5.28) has been less when the fuzzy based method was used.

5.7 Seamless Vertical Handover

In actual deployment scenario, it is experienced that the aforesaid horizontal handover is not sufficient to ensure reliable uninterrupted transmission of priceless health-data [70]. LoWPAN coverage can not be guranteed wherever the patients move with these wireless sensors. Typically, LoWPAN deployment confines within periphery of buildings. It may be required to move the patient to other health-care facilities. Patient’s movement in outdoor environment is also another possibility. Moreover, LoWPAN may become inaccessible within the building. Thus the major question is how mobility of sensor nodes can be handled beyond the coverage area of LoWPAN. One solution is a store-and-forward mechanism. But this mechanism can not be efficient for health-care applications where real-time data collection is required.

In the current state-of-the-art scenario, heterogeneous communication networks are in abundance. It is possible to get access to these heterogeneous networks (viz. UMTS, WiFi, WiMax) apart from the deployed LoWPAN as shown in Figure 5.30. These access technologies can fill-up the void wherever LoWPAN coverage does not exist. Therefore, a mechanism should be in place to ensure vertical handover seamlessly for un-interrupted health-data transmission across heterogeneous networks as shown in Figure 5.30. This handover should happen without perceptible service degradation while
maintaining minimal handover latency and minimal packet loss as health-care applications are data-sensitive and data-intensive.

![Figure 5.30: Vertical Handover](image)

### 5.7.1 Proposed Hand-Over mechanism

To overcome the difficulties mentioned earlier, here a vertical handover mechanism is proposed. For efficient vertical handoff, many network characteristics are required to be considered. In this work, following aspects are considered:

- **The state of the wireless access networks:** This includes the available received signal strength, link quality, bandwidth, network load.
  
  Received signal strength indicator (RSSI) and link quality indicator (LQI) are the most widely used criteria because it is easy to measure and is directly related to the service quality.
  
  Available bandwidth is a measure of available data communication resources in a network. Network load is a good indicator of traffic conditions in the access network. Both are important for delay-sensitive applications.

- **The state of the mobile node:** This includes the velocity and residual battery level of the sensor node.
  
  As the work is done with tiny sensor nodes, power consumption is a critical issue. When battery power is dwindling, it would be preferable to handover to a network which would not exhaust battery soon. Also, velocity of the moving node influences choice of the network.

- **User Preference:** This includes ranking of networks according to the user.
Personal preference of a user towards an access network could lead to the selection of one type of network over others.

Thus not only network parameters, but context information is taken under consideration also. It is proposed to use Media Independent Handover (MIH) protocol (commonly known as IEEE 802.21) in this vertical handover mechanism.

### Media Independent Handover

It facilitates vertical handover defining an abstract framework which helps in optimization and improvement of vertical handover performance by providing link layer information. In MIH protocol, media-independent handover function (MIHF) is the central entity. MIHF acts as an intermediate layer between the upper and lower layers. It coordinates the exchange of information and commands among various devices involved in making handover decisions and executing handovers [71].

In IEEE 802.21, three different types of services are defined. These services help MIHF users (i.e., mobility protocols) to access handover related information and deliver commands to the link layers.

**Media Independent Event Services (MIES)** It supports various types of events which help to detect when a handover is possible. There are several events such as link up, link down, or link parameters change that could be used to detect availability of a particular network or to sense the radio conditions to perform a handover.

**Media Independent Command Services (MICS)** Using this service, commands are sent from the higher layers to the lower layers in order to determine the status of links. These set of commands help to control and configure for gaining optimal performance or facilitate optimal handover policies. MICS provide dynamic information regarding link status and parameters to the mobility management protocols. Event generation may happen due to receipt of a certain command request from MICS and consequent actions are followed.

**Media Independent Information Services (MIIS)** It provides the mobile node with essential static information that may affect the selection of the appropriate networks during a handover. MIIS information is available to mobile node even before the authentication at the point of attachment is performed. It helps to check the security protocols, support of QoS, or other parameters before performing a handover.
Here, the proposed mechanism is intended for low-powered sensing devices, viz. Crossbow motes or sensor devices from Libelium Inc. Therefore, the protocol is customized to reduce signalling costs as much as possible making it lightweight and usable on tiny sensor nodes. Like [72], here the vertical handover mechanism has 3 phases: handover information gathering, handover decision making and handover execution as shown in Figure 5.31.

5.7.1.1 Handover information gathering

In periodic intervals, network sensing (or exploration) is carried out with the help of IEEE 802.21 services (viz. Media Independent Event Service (MIES) and Media Independent Command Service (MICS)). The mobile sensor node maintains a table of available network along with required network parameters gathered through Media Independent Information Service (MIIS). Since, the work encompasses around tiny health sensors which usually do not have GPS, geolocation is kept in abeyance.

5.7.1.2 Handover decision making

Once an event occurs in the link layer, next phase, i.e. handover decision making, is activated. Due to the presence of a number of criteria, the proposed mechanism utilizes Multi Criteria Decision Making (MCDM) and context-aware strategy to decide the candidate network. The context-aware strategy includes velocity of the sensor node and current status of the network which is retrieved from MIIS. It synchronizes the network usage pattern of the node and preference ranking of networks for making handover decision dynamically. Apart from the network parameters, velocity of the node is considered.
because WiFi cannot handle mobile node moving with very high speed. Instead, alternative networks with larger coverage area is preferred. This way unnecessary handoff can be avoided.

Weighted product model (WPM), a popular MCDM model (discussed in Section 4.5.1), is used for solving the decision problem. Here, it is used for selecting best available network because of its wide usage in multi-dimensional decision process due to its dimensionless feature.

Here, received signal strength, link quality, bandwidth of the network and residual battery power of the concerned node are benefit criteria as greater values are desired for these criteria. Network load is cost criterion as lower value is desired. If the user opined for a particular network, then it is chosen as most preferred alternative network. Otherwise, relative rating method is used to assign the weights to the criteria. The ratings and weights for criteria are decided according to the need of the application. In Figure 5.3, an example of rating to weight mapping is presented.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
</tr>
<tr>
<td>5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

In this work, signal strength and link quality are considered as main two criteria for good link. So, these are given first and second rating. The tiny nodes are power constrained. When the residual battery power is dwindling, a network should be selected in such a manner that will not cause faster battery dissipation. So, residual battery power of the node gets third rating. More network bandwidth and less network load are desired for establishing a good link. So, these two criteria are given fourth and fifth rating. Thus, the weights are assigned to the criteria and most suitable network is choosen using WPM.

5.7.1.3 Handover execution

After the decision is made, the sensor node executes the vertical hand-over using MICS service of MIH protocol. This is the last phase in the handover mechanism where control messages are exchanged between two networks to reroute the active link from one network to another. For the sake of heath-care applications, here soft handover is performed using mobile-controlled handover (MCHO) strategy.
5.7.2 Outcome

The implementation effort is done using existing testbed consisting 6LoWPAN enabled nodes and health-sensors from Libelium Inc. Primarily, the proposed mechanism is tested for 6LoWPAN-WiFi handovers. 6LoWPAN edge-routers are strategically deployed so that coverage does not become optimal. Thus, an ideal situation for vertical handover is created. 50 handovers are taken into consideration for this discussion.

In order to evaluate this vertical handover mechanism, few performance metrics are considered as given below.

1. Handover latency: It refers to the total time between the initiation and completion of the handover. Smaller handover latency is particularly beneficial for delay-sensitive health-care applications. Approximately 2 seconds latency on average has been observed.

2. Handover failure probability: A handover failure occurs when it is initiated but the candidate network does not have resources to complete the handover. It may also happen when the mobile sensor node moves out of the coverage of the candidate network before the handover is finalized. Within limited experimentations here, such scenarios have not occurred.

3. Packet drop: It refers to the ratio of number of packets delivered to the number of packets transmitted. In this experiment, 2% drop of packets have been observed. Because of sensitive health-data, effort should be made to make it null.

4. Throughput: Handover to a candidate network with higher throughput is preferable. As the initial implementation involves only 6LoWPAN and WiFi, no issue has been cropped up regarding throughput.

5.8 Discussion

In this chapter different mobility issues and scenarios of IP based wireless sensor network are discussed. The mobility management schemes are presented for low powered sensors within the sensor-cloud framework. 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-cloud framework and all of its resources to connect, share sensory data even when the nodes are mobile.

This implementation is further improved to avert handover in wrong direction. An intelligent mobility management scheme is proposed for 6LoWPAN enabled health sensor nodes. As chances of hand-over in wrong direction are eliminated, this fuzzy assisted scheme performs better than the previous threshold based mobility scheme in terms of hand-over latency, battery dissipation in mobile node and packet drop.

Last of all, a vertical hand-over mechanism is presented which enable tiny health sensor modules to transmit health-data irrespective of available communication technologies. So, there are no hindrance to offer uninterrupted remote health-care services.

Contributions of this chapter have been published in [70], [73], [74] and [75].

Next chapter discusses challenges about data collection from wide range of sensors. Also, solutions are presented for these challenges.