Seamless WSN Connectivity Using Diverse Wireless Links

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Abstract. Data transfer using wireless sensor networks (WSN) is bound by its limited coverage range. In order to communicate data beyond the coverage capability of a WSN link and make it pervasive, the authors here propose a method of information handover using heterogeneous wireless links for sensor-based data transmission. They draw on connectivity, one of the main features of a pervasive network. In the handover method proposed here, the WSN link is part of a wireless module which integrates various heterogeneous wireless links. All these wireless links are combined and coordinated using media independent handover functions (MIH) in accordance with the 802.21 Standard. As wireless modules have multiple wireless links, each module can communicate with the others using any one of the active links. When these wireless modules consisting of multiple links move beyond the communication range of the WSN link to maintain continuous connectivity the MIH in the module triggers the other wireless links to hand over the service with the help of access points in the surrounding area. The concept is discussed here in the context of a smart home application which transfers the sensed information continuously to a remotely located controlling station using the existing wireless infrastructure.

Keywords: IEEE 802.21 · WSN · MIH · Pervasive

1 Introduction

The wireless sensor network has become a prevalent network due to its simplicity of protocol stacking, network formation, durability, and suitability to a wide range of common applications involving unattended monitoring compared to the other wireless standards. When the WSN nodes are deployed to monitor an activity and to transfer the monitored data directly to a remote controlling station, the data transfer is possible as long as the nodes are in communication range of each other. However, as they move out of the physical range, communication gets interrupted.

As a solution to this problem, one can adopt various network topologies though each has its own capabilities, and an ideal solution may not be plausible. A strategy involving the Internet of Things (IoT) may be the best solution with modifications to the existing internet system. Nowadays, it is common to find wireless communication devices enabled with several wireless standards to facilitate communication with similar devices.

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For example, a mobile phone equipped with 3G, GPRS, Wi-Fi, or Bluetooth facility can communicate data through any device which has any one of these standards.

The current wireless environment motivates development of a method of achieving seamless connectivity between wireless sensor network nodes using other wireless standards. This paper proposes a method for integrating wireless standards into a single module and communicating in a coordinated manner. In this proposal, the IEEE 802.21 media independent handover functions are used as a platform in which wireless standards of varying types coexist and hand over the data between similar wireless modules. The IEEE 802.21-2008 is a standard [1] to provide handover facility between 802 and non-802 devices such as IEEE 802.11, IEEE 802.16, and 3G cellular networks. It consists of a set of functions called media independent handover functions which form the core regulating the overall functionality of such a stack. The media independent handover (MIH) function comprises an event, command, and information services to monitor network parameters and to regulate, validate and gather information for efficient communication between any two nodes.

In this proposal, the communication capabilities of the ordinary IEEE 802.15.4 based WSN node are extended using this feature of media independent handover functions.

According to this model, a wireless node consists of multiple wireless standards like IEEE 802.11 (Wi-Fi), IEEE 802.16 (Wi-Max), and 3G cellular interface, along with the IEEE 802.15.4 (WSN) which is called a combined wireless node (mobile node) as shown in Fig. 1. The MIH functions direct the overall interaction between them and enable other wireless links to perform a handover whenever a node moves out of range. Such an enabled link, with the assistance of its home network, transfers the data to the destination.

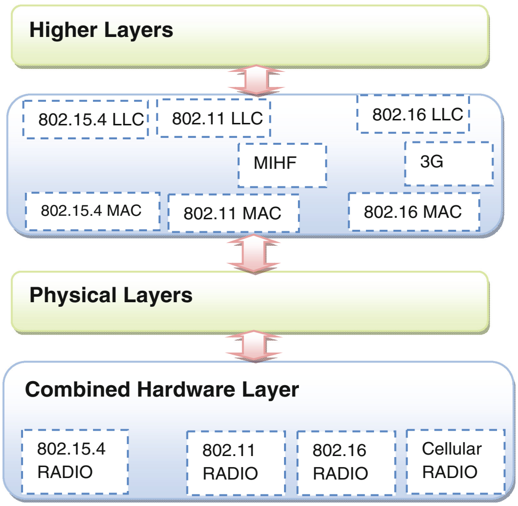

Fig. 1. Mobile node architecture

2 Literature Review

The handover feature of MIH has appeared in several previous works. Kim, Moon and Cho [2] discussed a handover method between Wi-Fi and Wi-Max links using a prospective candidate for handover. Introducing a new framework for MIH, as in the works of Lim and Kim [3] as well as Ali-Yahiya and Bullot [4] provides faster handover between 802 links. The cross-layer design for the stack in Vulpe, Obreja and Barbu [5] provides handover between the 802 and cellular networks. In this example, the new network selection policy engines and mobile node architecture are discussed. The Qualnet simulation [6] for mobile node handover deals only with limited parameters. For efficient handover, an information server and a new architecture and prototype are evaluated in Fratu, Popovici and Halunga [7]. Their results show optimum processing time in handover and vary based on the application. To collect the handover information from the information servers effectively, center node architecture is proposed in Andrei, Popovici and Fratu [8]; this system collects information from all servers to update the network as in Popovici, Fratu and Halunga [9]. Handover techniques are similarly analyzed in RB [10], Chukwu [11], and Fallon and Murphy [12].

Until now, MIH features have been used to provide handover between 802 or cellular networks. In this paper, the MIH is used to trigger the handover process whenever the WSN node is about to lose connectivity with the destination to continue the data transfer. In this case a wireless node (the MN) is a portable wireless unit with a stack consisting of multiple wireless links and MIH.

3 Specifications

3.1 Technical Aspects

The technical aspects of this work mainly involve the development of architecture to support handover between the WSN (802.15.4) and other wireless links by having them all reside within the same module. The wireless module that integrates all the wireless links and MIH and coordinates them is called a combined wireless module or mobile node (MN). The media independent handover functions can provide three set of services: event, command, and information services. The event services deal with reporting of events related to the change in link behavior, link status such as link up or down, or any changes in the link parameters of the communication link.

Media independent command services are generated by any higher layer which enables them to control the lower layers (PHY, DLL) to set up the network connectivity based on the reported parameters of the event services. In this way, command services enable the user to select the best network for the task.

As the IEEE 802.21 standard does not specify the handover service for WSN, the architecture has an internal partition to separate the communication traffic of other wireless links from the WSN link. The MIH service has another important terminal called the Information Server which maintains the database of all the wireless nodes to share with the access points. Information from all the networks operating within a physical region including their network type, address information, and services offered will be stored in the server to make it available during the time of handover.

The combined wireless module (MN) proposed here has an architecture that consists of a union of heterogeneous radio links such as 802.11, 802.16, 3G cellular, or 802.15.4 on the same board as integrated hardware as depicted in Fig. 1. The data link layer consists of link-specific MAC and LLC along with MIH functions. The MIH functions are used to regulate and coordinate between these wireless links for information transfer. The higher layers are defined according to the user's preference.

As per this protocol for data transfer, initially the nodes communicate via WSN link (802.15.4) for sensor-based data transfer. Meanwhile, the MIH within a module continuously monitors the link status using its service functions. If any of them moves out of its limited coverage range, the data communication will be interrupted. During such a situation, in order to have continued connectivity between the modules, the application in conjunction with the MIH functions in the module trigger the handover process by enabling the other wireless links like 802.11, 802.16 or 3G because they offer a better coverage range than the WSN link and attempt to resume connectivity with the destination.

In order to achieve this, the information about all the network links must be dynamically maintained in a central database called the information server (IS) located such that it must be reachable from any one of the wireless links in a module at any time. The proposal therefore emphasizes the need for an improved network formation procedure rather than the one described by IEEE in January 2009 [1].

The proposed network formation method suggests using the wireless module to transfer all its network parameters and link specifications to the coordinator as soon as it joins the WSN coordinator or the access point. The coordinator transfers this information to the information server. Additionally, the server periodically transmits the status of all the wireless modules to indicate the network status. This enables all the network elements to recognize each other, as there is a good chance in a dynamic network that some of the nodes may become inactive in the due course of network formation. The periodicity of this transmission can be configured based on the required quality of service. The transmission of this information is made in a link-independent manner to enable all modules to receive via any link. As a result, all the nodes will confirm connectivity to any particular access point. This process eliminates the need to search for a potential candidate to perform the handover as the link goes down. When compared to the existing method of MIH handover as described in IEEE [1], the proposed method also proves to be power efficient due to the reduced number of communication steps.

3.2 Technical Aspects

We will now describe the technical aspects of this proposal using the example of a smart home to automate the process of monitoring the various events in the home such as variations in temperature, pressure, and humidity conditions using WSN-enabled sensors and reporting data to a remote monitoring station. In such a scenario both integrated wireless modules are equipped with multiple link technologies. If a user wants to access the sensor-monitored data while traveling in a car with a controlling station, communication is not possible beyond a certain range of the WSN link. Nevertheless, to facilitate user access to the data continuously, we exploit wireless links operating near the home where sensor-based data is generated and link to the user's new location where data is collected. As a link goes down due to the user's movement, the MIH within the module continuously monitors the link status. As the node transmits its link details to the server and they are received, the network information from the information server will be continuously updated. As a result, as soon as the signal strength goes below a certain threshold, the MIH triggers the handover by enabling the IEEE 802.11 link which joins the appropriate access point and tries to serve the node. If the node is beyond the coverage range of this link, a higher order link is enabled to perform the data transfer. The selection of the link in this proposal is made as in the order 802.11, 802.16, 3G.

Figure 2 depicts a scenario in which the sensor data from the home must be transferred to the controlling station using a WSN link. As the collecting mobile node (MN) moves away from the coverage range, in order to have continued connectivity, the surrounding wireless infrastructure is utilized. The newly enabled link associates with the homogeneous point of service (its access point) and communicates the data without interruption. Each node has distributed data in its architecture to exchange the data collected from various links. As an example, whenever the WSN link goes down to the threshold, the 802.11 link of the same wireless module gets enabled by the MIH and associated with the 802.11 access points present in the surroundings and then transfers the data to the controlling station. Thus, data communication continues uninterrupted. In case the node is not reachable through the 802.11 link, the node can enable other links with higher coverage range like Wi-Max or cellular and try the same procedure. This quicker handover is made possible by the proposed network formation method.

The network information server is located at a place where all the nodes can conveniently reach it by any one of its active links. The information server has access to the Internet backbone; thus any link like Wi-Fi, Wi-Max, or cellular that can access the

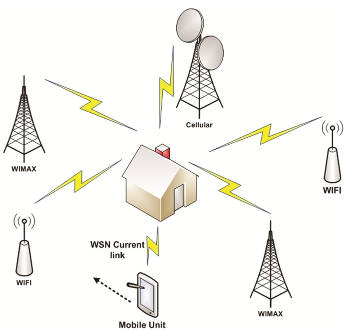

Fig. 2. Smart home scenario

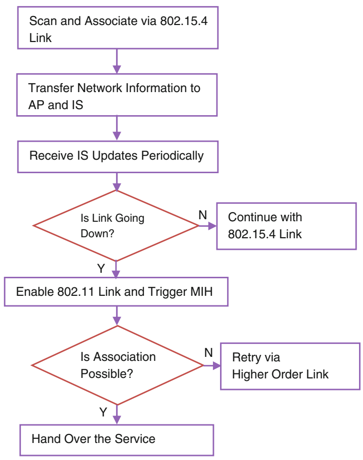

Fig. 3. Flow chart for implementation of network formation

Internet will be able to access the information server. Figure 3 shows the sequence of the network formation handover scheme.

4 Analysis of Handover Delay

In this section, we investigated the delay involved in the handover of information between the links. The handover delay as per the 802.21 based handover process is due to a series of message exchanges between the initiating node, its point of service/access point, the information server and the prospective candidate network [1]. This is necessary to acquire the network parameters essential to knowing about the future point of service. Each of these messages has a fixed length. Whenever a node finds the signal strength falling below the threshold, it triggers the handover process by transmitting a packet to collect the list of possible links in the surrounding area to which it can connect. When the message reaches the receiver, it sends the acknowledgment; in this way multiple packets are exchanged between multiple network elements [12]. Here we analyze the delay involved in performing the handoff as per the 802.21 handover procedure.

A node starts to transfer the data at an initial time T_{init} .The data generation time T_{gen} depends on the amount of data to be transmitted and the data transfer rate of the link. The transmitted data reaches the receiver after a certain propagation delay T_{pron} When this data reaches the receiver it sends an acknowledgement after turnaround time T_{TA}. Thus the total delay involved in sending a part of the handover process takes

$$\mathrm{T_{init}} + \mathrm{T_{gen}} + \mathrm{T_{pro}} + \mathrm{T_{TA}}$$

Performing handover after N message transmissions (assuming acknowledgments are received within the short interval) is therefore expressed as follows:

$$T_N = T_{init} + \sum_{i=0}^{N-1} T_{gen}(i) + T_{pro}(i) + T_{TA}(i)$$

However, with the proposed method of network formation, as soon as a node associates with the coordinator, it has to transfer all its link details to the coordinator/point of service. This information will be exchanged between the point of service and the information server (IS). In turn, the information server periodically transmits the network information to all the nodes independent of the link. The nodes will have a ready reference to all the link parameters as a result; the handover process does not involve the exchange of query information. Thus, the total delay involved in handover will be as follows:

$$\mathrm{T_{pro}} + \mathrm{T_{gen}} + \mathrm{T_{TA}}$$

Figure 4 shows the performance delay in the handover process. We compared the delay for each handover command transmission in the conventional MIH as in IEEE 802.21 and the proposed method. In this simulation, a random delay is considered between each command transmission for both cases. The graph shows that the delay increases for each command transmission in the conventional method, whereas delay is held almost constant in the proposed method.

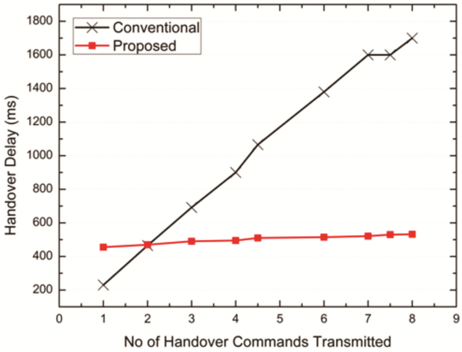

Fig. 4. Comparison of handover delays

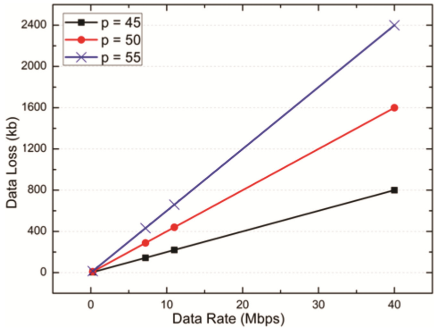

Fig. 5. Data loss for several wireless standards

If multiple nodes request handover at a common access point, the total time needed to process all the requests will be the sum of the handover duration for the individual nodes. But in the case of handover by the method proposed here, which precedes proper network formation, there will not be any need to request the access point because the network information will be periodically updated by the information server. As a result of this the total delay in processing the handover requests of 'N' number of nodes will be the same as the duration of a single node.

Similarly, by considering the buffer capacity of each of the wireless transceivers, the amount of time involved to transmit a data packet requires transmission attempts based on data buffer size.

In the case of the proposed handover scheme, the number of transmissions required to perform the handover is lesser, which leads to minimum power consumption. Yet another parameter investigated here is the amount of data loss that occurs in different wireless standards due to delay in handover. The key factor to initiate the handover process is signal strength falling below the minimum threshold level. Once the signal falls below the threshold level, the service is terminated. However, in this case, we considered a margin signal strength 'P' above the minimum threshold level of the signal. Below the threshold, the received data is no longer useful as the BER is unacceptable.

In such a case, the time spent receiving the signal between these two events without performing the handover results in unnecessary power consumption without contribution to valid data reception. If P_{Thr} is the minimum threshold of signal strength and P is the marginal signal strength above the threshold, then for different wireless networks offering various data rates (WSN 250 kbps, Wi-Fi 11 Mbps, Wi-Max 40 Mbps, 3G 7.2 Mbps), the amount of data loss in a conventional MIH handover can be calculated as follows:

$$Data\ loss = \frac{P - P_{Thr}}{Total\ time\ spent} * Data\ Rate$$

The parameter Total Time Spent is the total duration of data communication. As shown in Fig. 5 the simulation is done for different wireless standards by considering their data rate and various margin values ‘P’ by considering the threshold (P_{Thr}) as 40 percent. It is clear from the graph that, for lower marginal values of signal strength, the amount of data loss in all the standards is less compared to situations of higher marginal values, due to the decrease in time required for handover when the signal strength is approaching threshold. Thus, the improvement of handover efficiency lies with the quickness of the algorithm performing the handover to prevent data loss. This data loss is proportional to handover delay due to lack of network information. In the proposed method, the network handover process is simplified by the periodic transmission of network information.

5 Results

As indicated in Table 1, the conventional method of handover using the media independent handover functions as in IEEE 2009 [1] would require more handover time due to the need to exchange several commands between access point, mobile node and IS.

Table 1. Handover performance

Handover Method	Parameter	Performance
Conventional	Handover time	$T_N = \sum_{i=0}^{N-1} T_{pro}(i) + T_{gen}(i) + T_{TA}(i)$
	Handover time at access point due to N nodes	$N * T_N$
	Handover command TX time	N*(Data_ in_one Command / Buffer size)
Proposed	Handover time	$T_N = T_{pro} + T_{gen} + T_{TA}$
	Handover time at access point due to N nodes	T_N
	Handover command TX time	Data_in_one Command /Buffer size

Thus, the total time is the sum of the transmission time for all commands. In the proposed handover, the nodes have the network information and, as a result, require a single command transmission time. Because of this the time to serve multiple nodes at the access point is the same as the handover time, whereas in the conventional method it is additive. Similarly, due to the need to transmit multiple commands in the conventional method, time to transmit the handover command for the same sized data packets and buffer is higher.

6 Conclusion

The proposed scheme of handover services for wireless sensor networks using multiple wireless links and media independent handover functions is a novel method as it addresses the integration of wireless modules within an MIH based stack.

It works efficiently due to the concept of a new network formation method. The efficiency of the handover with the proposed network formation method is reflected in reduced handoff delay when compared to conventional MIH-based handover methods. The proposed method eliminates the burden at the access points during multiple handover requests as information from the information server is periodically transmitted and the wireless modules acquire enough information to manage the handover with a minimum number of transmissions. The number of periodic transmissions can be configured by considering the required quality of service.

This scheme also reduces use of power by reducing time and reduces data loss by reducing handover delay.

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