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Error Rate Based Analytical Switchover Approach for Multi-Homed Body Sensor Networks

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Abstract

For patients who have undergone cardiovascular surgery it is necessary to monitor vital signs such as respiration, oxygen in the blood, temperature, and electrocardiogram (ECG) in real time. As well as the sensor device, many existing solutions need a bulky coordinating unit like a PDA located on the patient for network communication. In this paper we investigate an infrastructure mode based approach in which the wireless sensor, communicates directly with the wireless access point. Our investigation particularly focuses on how the emerging technology, Media Independent Handover (MIH) can be used by the wireless sensor to manage path migration. Since MIH does not implement the physical handover we also use the mobility enabled Stream Control Transmission Protocol (SCTP). We analyze how MIH link quality triggers, in particular Error Rate, can be used to improve SCTP switchover performance in body sensor networks.

Keywords: SCTP, MIH, Body Sensor Network, Switchover

1 Introduction

An emerging area of deployment for wireless sensor networks is medical vital sign monitoring. Such an approach enables caregivers to remotely monitor the status of their patients in a hospital or health centre using wearable wireless vital sign sensors. Vital signs sensors are used to monitor respiration, oxygen in the blood, temperature and electrocardiogram (ECG) of the patient. This technology can be extended from hospital or health centre to the home, work or any other public location. In an emergency disaster scenario, the placement of such sensors on victims would enable medical staff to efficiently prioritize attention given to casualties [4]. In body sensor networks, life-critical data should be delivered reliably in real time. Moreover, life-critical data cannot be aggregated by the network as the data is gathered from different patients.

Many existing solutions for body sensor networks use a bulky coordinating unit like a Personal Digital Assistant (PDA) located on the patient to provide communication with back end systems using cellular networks [1][6][8]. This paper investigates how multi-homing technologies, which use multiple underlying network connections for end to end peer communication, can be used to guarantee the delivery of life-critical data. In particular we investigate how the emerging MIH standard can be used to minimise data delay and loss during network migration. In our approach the sensor node communicates directly with the wireless access network without the need for the coordinating unit on the patient. As Bluetooth signal range is limited, performance degradation is expected as the patient migrates from the coverage of one AP to another. Our approach is focused on pre-empting this degradation by optimizing the switchover performance.

As this paper investigates the reliable transmission of life-critical data the reliable transport layer protocol SCTP [7] which incorporates multi-homing capabilities is used for implementing network

mobility. We disable the switch management functionality in SCTP and introduce our version of the IETF's new standard MIH [5] to optimize switchover time for body sensor networks. Our MIH implementation uses one of the link metrics suggested by the National Institute of Standards in Technology, *Path Error Rate*, as a switch trigger. We compare the performance of our approach against standard SCTP controlled path migration strategies. Results presented indicate that our approach gives better performance.

This paper is organized as follows; Section 2 discusses the related work. Section 3 explains the technologies which are employed. Section 4 describes the test configuration and analyzes the results. Section 5 discusses the conclusions.

2 Related Work

There are number of solutions to optimize the Body Sensor Networks performance. In [11], a combined hardware and software platform for medical sensor networks, called *CodeBlue* is demonstrated. It provides protocols for device discovery and implements multihop routing. The solution includes priority *CodeBlue* sensors. A limitation of this system is that it is connectionless and guaranteed delivery of data is not implemented.

In [1], the development of a sensor node based body sensor network hardware which uses a PDA as a base station, is represented. In [8], a heart monitoring system which is ECG signals are transmitted to a PDA to transfer the signals to the central server through the coordinating unit, is demonstrated. In [6], a wearable body sensor system which is called as MIThrill is demonstrated. The system uses a cell phone or PDA to get ECG data, Global Positioning System (GPS) position, skin temperature and galvanic skin response. All these solutions require the use of a bulky coordinating unit deployed on the patient. Such an approach is inconvenient for patients who make be weak following extensive surgery. Our approach uses Bluetooth in infrastructure mode connects the body sensors directly to the local network without the need for a coordinating unit on the patient.

In [7][12], SCTP is defined as a reliable TCP-friendly transaction-oriented transport layer protocol defined by the IETF. The key features of SCTP, multi-homing and multi-streaming, make it possible for transmission of real-time data in heterogeneous environments. SCTP provides link back-up in the event of primary path failure where the back-up link is used for data retransmission when the primary path is active. SCTP's handover mechanism is implemented when the link failure occurs. If a primary path failure is detected data transmission is switched to back-up path.

In [13], an overview of IEEE new standard MIH (802.21) which provides the seamless handover between homogenous and heterogeneous network interfaces is provided. In [3], another MIH based SCTP switchover mechanism is investigated. All these works indicate that using MIH characteristics to manage switchover decisions and uses SCTP to implement handover gives better performance.

3 Technology Overview

3.1 Media Independent Handover (MIH)

IEEE 802.21 standard also known as MIH is an evolution for all networks, providing capabilities to detect and initiate handover from one network to another. MIH does not implement the switchover in itself. It needs a protocol to implement the switchover like SCTP. Instead of that it provides necessary information for switchover like link states, neighbour networks, neighbour maps, etc. The MIH Function makes the network handover possible. The MIH Function consists of 3 important elements:

Event Service – The event service provides event facilities corresponding to dynamic changes in link characteristics. The defined events include Link Available, Link Up, Link Parameters Change, Link Going Up, Link Down, Link Going Down, L2SDU Transmission Status, Event Rollback, etc.

Command Service – The command service refers to the commands sent from the higher layers to the lower layers. It includes the commands from upper layer to MIH (e.g. upper layer mobility protocol to MIH, etc), and from MIH to lower layer (e.g. MIH to MAC, or MIH to PHY).

Information Service – The information service provides access to static information such as neighbour maps, helping in network discovery. This could include link layer parameters such as channel information, MAC addresses, security information, etc.

3.2 Stream Control Transmission Protocol (SCTP)

SCTP is a reliable transport layer protocol defined by the IETF as a proposed standard. It provides ordered or unordered delivery optional and it preserves message boundaries. The SCTP's main features are multi-homing and multi-streaming capabilities. Extensions for partial reliability and dynamic address reconfiguration make it possible for SCTP to adapt to the differing needs of applications and be dynamically reactive to changing network conditions.

3.2.1 Multi-Homing

SCTP enabled endpoints may communicate with each other via multiple IP addresses within a single connection where multiple network devices are available. A connection between two endpoints is known as an association within SCTP and an association is identified by the transport addresses of the endpoints. Details of each endpoint's information like transport addresses, IP addresses and an SCTP port, are exchanged between the peers at start-up, from which a primary path for data transmission is selected. The additional paths provide link backup in the event of failure on the primary path and are used for data retransmission. Non-primary paths are monitored during the course of the association to verify reachability.

3.2.2 Multi-Streaming

SCTP supports the multi-streaming in each direction on a single association. Each stream is logically independent of all other streams. If the one of the streams is blocked, it does not affect the other streams in an association. This is important because it does not cause a “*head-of-line blocking*” problem and it gives the better performance on association.

3.2.3 Path Switchover

At SCTP association beginning, one of the physical paths is identified as the primary path and the other one is identified as the secondary path. This primary path is normally used for transferring packets (data chunks) from one endpoint to another one. When the primary path failure occurs, the secondary path will be selected as primary path and SCTP continues to send the packets from this path. The SCTP path management uses heartbeat packets to control the reachability of each destination. If the acknowledgement is received by the sender from its destination endpoint within the designated heartbeat interval the address is indicated as “active”. If no data chunks have been sent to a destination address within the designated heartbeat interval the address is indicated as “idle”. If a SCTP sender does not receive an acknowledgement for a SCTP data chunk from its destination address within the time of Retransmission Time-Out (RTO), the sender will think that this data chunk is lost. If a number of data chunk losses occur and if that number exceeds the SCTP parameter Path.Max.Retrans (default 5), the address will be indicated as “inactive” by the sender and it will not send any packets until it becomes active again. Consequently, RTO is an important factor for switchover and the quality of the protocol.

3.3 Bluetooth Technology

Bluetooth is a low cost, low power, short range technology, originally developed as a cable replacement solution to connect various devices such as mobile phone handsets, headsets and portable

computers. Bluetooth is often described as a Personal Area Network (PAN) technology, and has also been used to connect to various sensor devices. The Bluetooth specifications are managed by the Bluetooth SIG (Special Interest Group). In addition to the core specifications, The Bluetooth SIG has specified a number of profiles. Each profile describes how a particular application can be implemented including which parts of the Bluetooth protocol should be use to support the profile [16].

4 Investigation of Switchover Strategy

4.1 Experimental Setup

Figure 1 illustrates the test configuration in which two laptops, laptop 1 representing a body sensor client and laptop 2 representing a back end server, are connected via Bluetooth adapters. The body sensor client was configured with Windows XP and the server laptop was configured with Ubuntu Linux. Both laptops were configured with SCTPLIB [9]. The sensor client and server were multihomed through 2 sets of Class 1 USB Bluetooth adapters. The sensor client was configured with IP addresses 192.168.50.1 and 192.168.50.2. The server was configured with IP addresses 192.178.51.1 and 192.168.51.2.

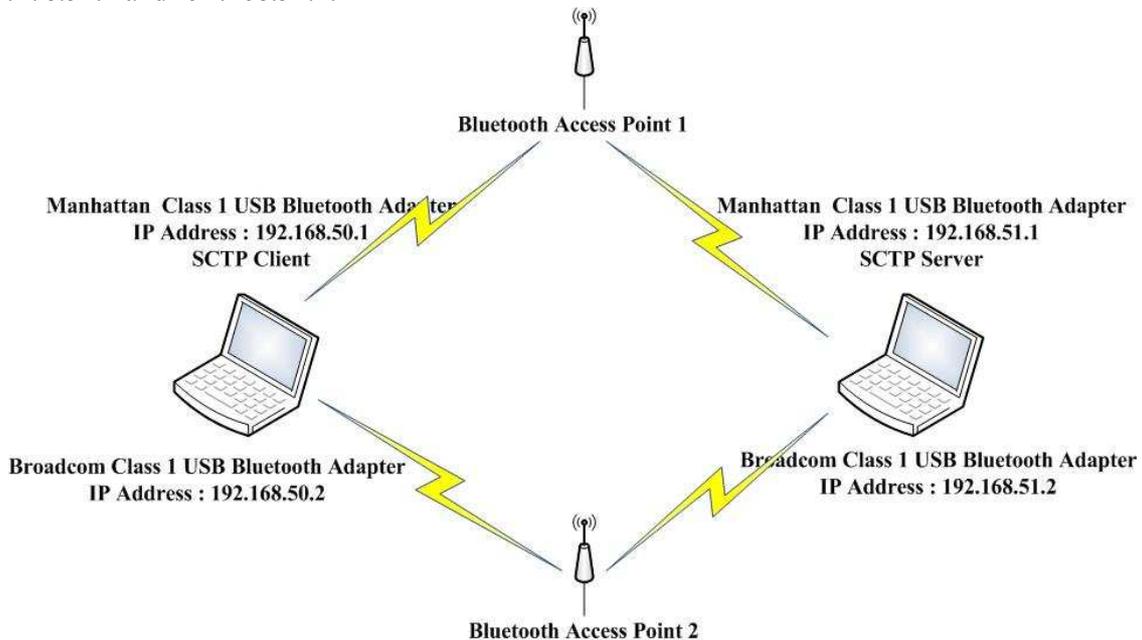


Figure 1: Test Network Configuration

All IP addresses were statically configured to ensure that 2 distinct paths were created. Each test was initiated with Path1 (192.168.50.1 - 192.168.51.1 with Bluetooth Access Point 1) as primary and Path 2 (192.168.50.2 - 192.168.51.2 with Bluetooth Access Point 2) as secondary.

In order to dimension Bluetooth network behavior to use in further simulated studies 20 baseline tests were executed. Each test involved pinging an Access Point (AP) with 32 bytes of data per second. The tests were started adjacent to the Bluetooth Access Point 1. The mobile client then moved at slow walking pace, approximately 1m/sec, and a distance of 100m. Frontline FTS4BT Bluetooth Protocol Analyzer and Sniffer used to sniff all the packets on the association. It decodes all Bluetooth protocol. It decodes and displays multiple protocol layers of multiple data frames simultaneously in real time. The values which are taken from Bluetooth Protocol Analyzer and Sniffer device are used in further simulated studies.

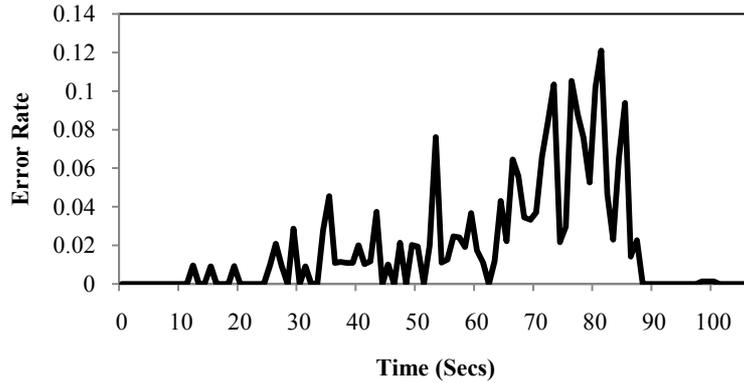


Figure 2: Error Rate

As the mobile node moves out from the coverage of the AP the error rate increases and results in intermittent network connectivity. Figure 2 illustrates the error rate increasing when the mobile node moves from coverage of the AP for the selected test. Link delay follows the similar pattern with error rate for selected test.

4.2 Analytical Smoothing Work on Error Rate

Data smoothing techniques are used to create an approximating function that attempts to extract real trends and patterns while eliminating noise. In order to decide the best switchover time, we implement the some analytical algorithms on the error rate to smooth the values. Below are some of the available smoothing methods which gave us the best results for our approach.

4.2.1 Olympic Smoothing Algorithm

The Olympic algorithm is another kind of the Moving Average algorithm. The high and low values of data set are removed, and the average of the rest values is taken. This algorithm is very effective at removing high-frequency noises, but it can still reduce amplitude like the Moving Average algorithm. Figure 3 illustrates the smoothed values of error rate with Olympic algorithm [14].

$$y'_k = \left(\sum_{k=1}^n y_k - (\max(y_k) - \min(y_k)) \right) \frac{1}{n-2}$$

4.2.2 Median then Mean Smoothing Algorithm

The “*Median*” is the “middle” value in the list of numbers. The numbers have to be in numerical order to find the median, and then middle of the numbers is median. The “*Mean*” is the “average” of the values, where you sum up all the numbers and then divide by the total number of numbers.

In this algorithm we smoothed the values like firstly we calculate the median of the values (11 values) and then we took their mean. Figure 4 illustrates the smoothed values of error rate with median then mean algorithm.

4.2.3 Exponential Moving Average Smoothing Algorithm

A Moving Average is the technical indicator that shows the average value of a particular currency pair over a previously determined amount of time. An Exponential Moving Average, which can also be referred to as an exponentially weighted moving average, applies weighting factors which decrease exponentially. The weighting for each older data point decreases exponentially, giving much more importance to recent observations while still not discarding older observations entirely.

The degree of weighing decrease is expressed as a constant smoothing factor α , a number between 0 and 1. α may be expressed as a percentage, so a smoothing factor of 10% is equivalent to $\alpha = 0.1$.

Figure 5 illustrates the smoothed values of the error rate with Exponential Weighted Moving Average [15].

$$y'_k = \alpha y_{k-1} + (1 - \alpha)y'_{k-1}$$

4.2.4 Random Smoothing Algorithm

This algorithm is more effective when each data has no relationship to the pattern in the previous data. Under this condition, the best prediction for the next value in a series is simply the average of all previous data points. Figure 6 illustrates the smoothed values of error rate with Random algorithm.

$$y'_k = \frac{1}{k-1} \sum_{j=1}^{k-1} y_j$$

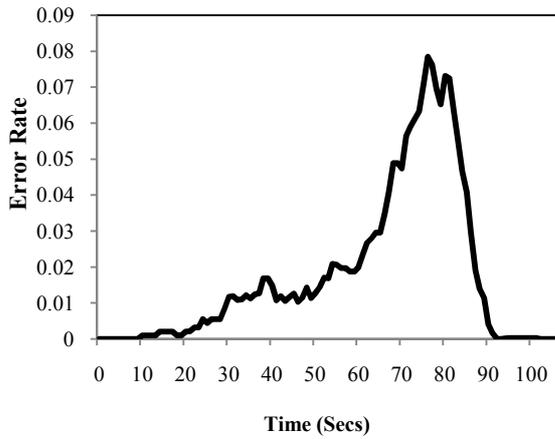


Figure 3: Olympic Algorithm Smoothed Error Rate

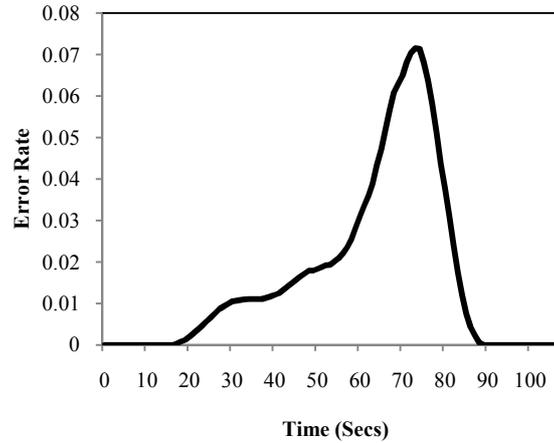


Figure 4: Median then Mean Algorithm Smoothed Error Rate

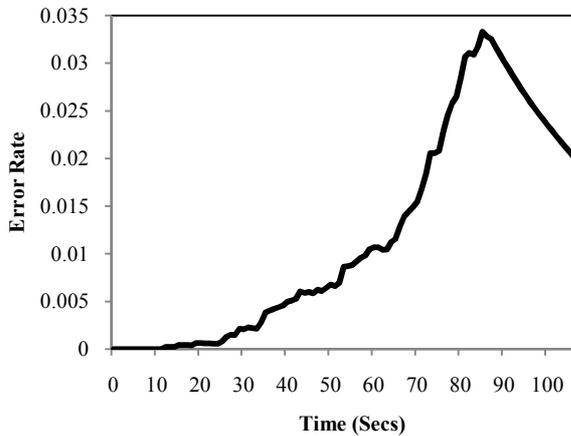


Figure 5: Exponential Moving Average Algorithm Smoothed Error Rate

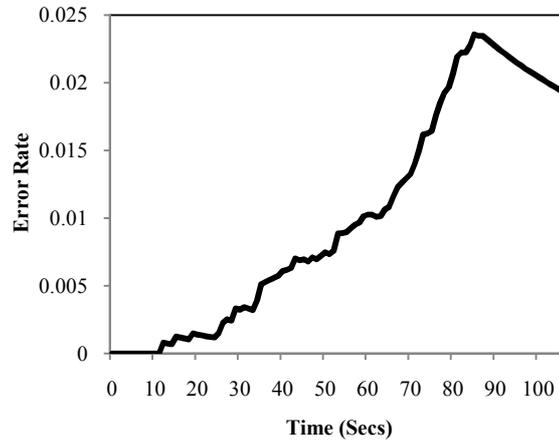


Figure 6: Random Algorithm Smoothed Error Rate

4.3 Simulation Setup & Results

In order to accurately analyze the performance of a SCTP Switchover performance in Bluetooth Networks an NS2 [10] simulation was created which utilized the University of Delaware's SCTP module [2]. The simulation used the results of the previously described experimental study. Figure 7 illustrates the simulation topology which reflects the experimental test configuration described previously. Node S and Node R are SCTP sender and receiver respectively. Both SCTP endpoints

have two addresses. R1,1, R1,2, R2,1, R2,2 are routers. The implementation is configured with no overlap between two paths. Node S begins to send FTP data to Node R after 0.5 seconds.

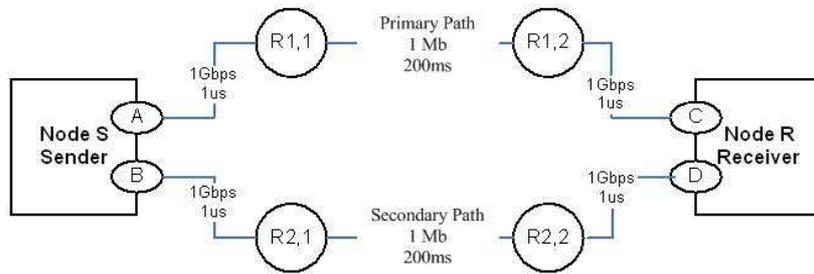


Figure 7: Simulation Configuration

4.4 Evaluation of Standard SCTP

In this section we analyzed the data throughput for the default values and smoothed values by different algorithms. It has been suggested that PMR 0 gives best performance, therefore, for this simulation, we use standard SCTP's parameter PMR from ranging 0,1,2 to analyze the total amount of data transmitted for each algorithm. Figure 8 presents the total amount of data transmitted for PMR 0, 1, and 2 values for the original error rate values.

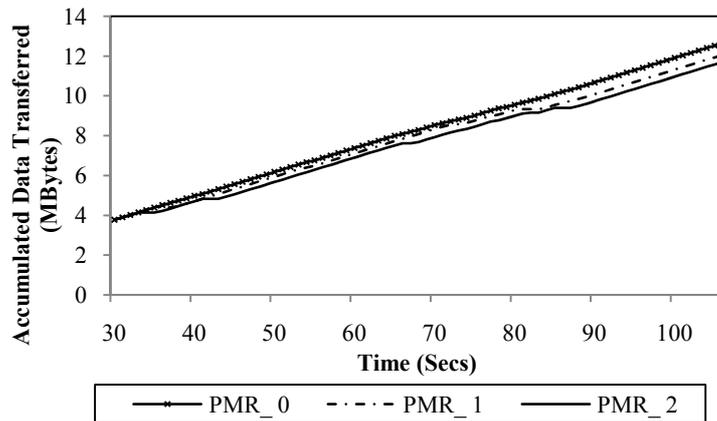


Figure 8: Accumulated Data Transferred for PMR_0, 1, and 2

4.5 Evaluation of MIH Based Approach

For each test the default SCTP based switch functionality was disabled by setting an arbitrarily high PMR value of 50. Over a 110 seconds period, the tests were executed with explicit switch over times ranging from 10, 20, 30, 40, 50, 60, 70, 80 and 90 seconds. The figures below illustrate the total amount of data transmitted for each of the tests of each algorithm.

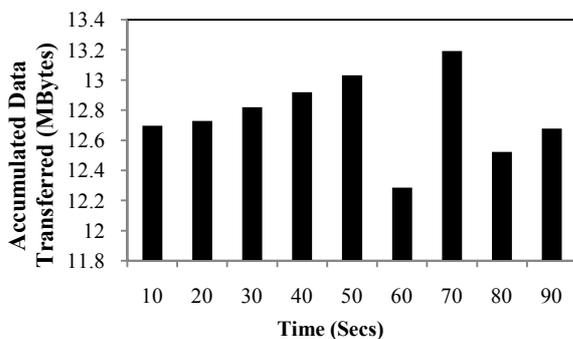


Figure 9: Olympic Algorithm Accumulated Data Transmitted in Different Switchover Times

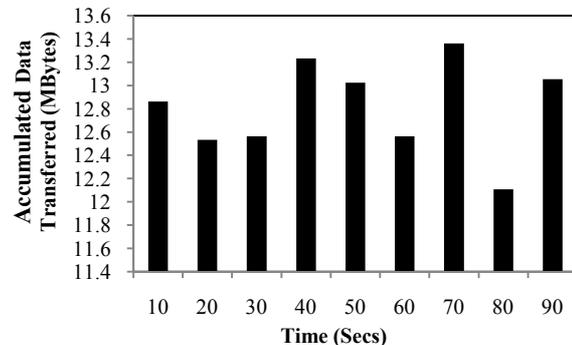


Figure 10: Median then Mean Algorithm Accumulated Data Transmitted in Different Switchover Times

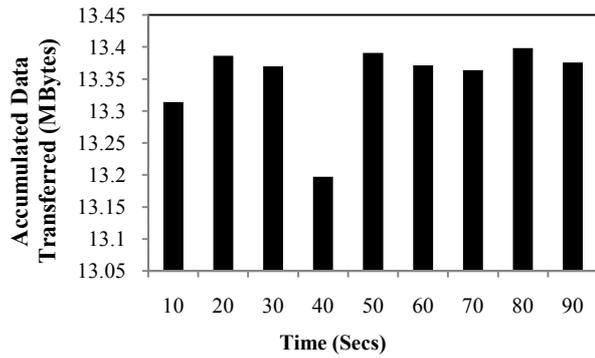
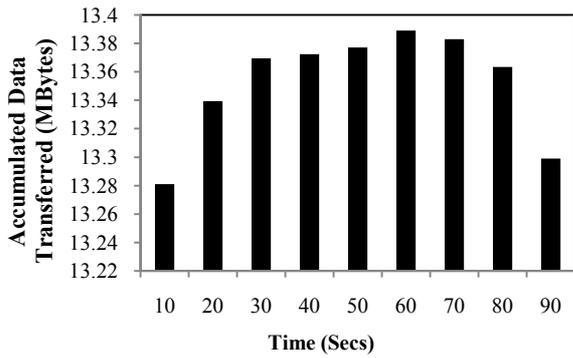


Figure 11: Exponential Moving Average Algorithm Accumulated Data Transmitted in Different Switchover Times

Figure 12: Random Algorithm Rate Accumulated Data Transmitted in Different Switchover Times

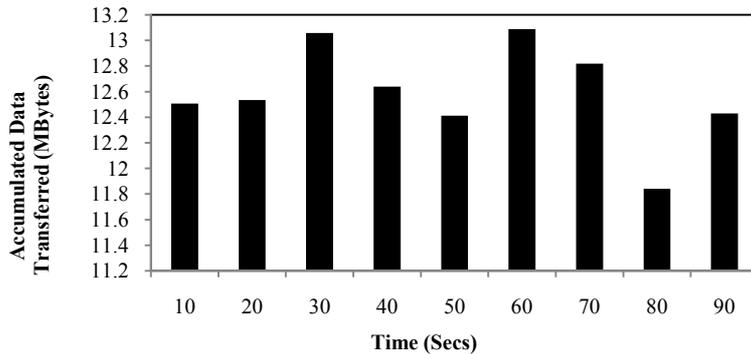


Figure 13: Original Values Accumulated Data Transmitted in Different Switchover Times

As seen from the graphs, total amount of data is changing sharply for different switchover times in different algorithms. Especially in Figure 13, original error rate values, explicit switchover times give sharply different total amount of data transmitted. In Figure 11, smoothed values by Exponential Moving Average Algorithm gives better performance than other. And it can be easy to decide the switchover time with this algorithm.

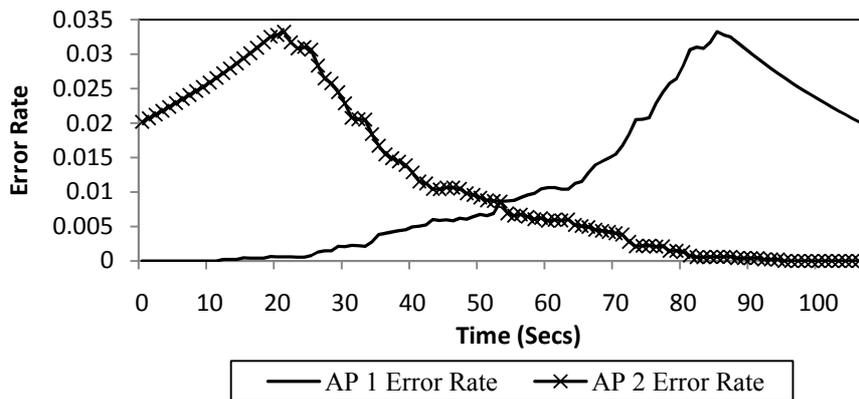


Figure 14: Error Rates (Smoothed by Exponential Moving Average Alg.) of Access Points

As the Exponential Moving Average Algorithm gives the most effective results we select it for use in further studies. Figure 14 shows the Smoothed Error Rate values by Exponential Moving Average algorithm of both access points. Deciding to switchover before the Error Rate intersection between two access points means that switching a path with high Error Rate will give higher data loss before the switchover. In contrast, deciding the switch after the Error Rate intersection between two access points means switching to a path with lower Error Rate, these results in lower data loss but long switchover delay. By using MIH oriented characteristics such as Error Rate the switchover can occur at the point of intersection, thereby improving performance.

5 Conclusion & Future Work

In this paper we proposed an infrastructure approach to body sensor network communication, in which the sensor communicates directly with the wireless access network without the need for a coordinating unit on the patient. We analyze how MIH link triggers, in particular error rate, can be used to improve SCTP switchover performance. Results indicate that the performance of the standard SCTP switchover mechanism is unsatisfactory. Having experimentally recorded the packet error rate, we implement various smoothing algorithm to determine optimal switchover time. Results presented indicate that Exponential Moving Average smoothing algorithm provides an optimal switchover time. Finally, we illustrate that our MIH based switchover provides significantly better performance than the standard SCTP's approach.

Future work will focus on the optimization of other MIH link triggers suggested by the NIST, together with the development of an algorithm to implement the seamless switchover for body sensor networks

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