Evaluation of the SCTP Optimal Path Selection with Ant Colony Optimization Probabilistic Equation Implementation

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Abstract—**This paper evaluates the proposed SCTP optimal path selection mechanism which implements the Ant Colony Optimization probabilistic equation. The proposed mechanism uses three parameters, which are the path delay, RSSI level at the mobile node and the RSSI level at the corresponding node, as the decision criteria. A cross-layer architecture is proposed to obtain the value from the Physical layer. In addition, a new parameter for the SCTP Heartbeat chunk is introduced in order to share the RSSI information between the nodes in the SCTP association. A brief comparison between using two parameters (path delay and RSSI at mobile node only) and three parameters (plus RSSI at the corresponding node) is also included. The experimental evaluations show that the proposed mechanism is able to select the optimal path.**

Key words: *SCTP, handover, path switching, optimal path selection, heartbeat chunk*

I. INTRODUCTION

The recent advancement in vehicular technology have given birth to very high speed land vehicles such as high speed bullet trains which have the velocity that spans up to more than 300km per hour. The existence of such technology creates an environment where the users of mobile or wireless networks enters and leaves the communication cells which are provided by the service providers frequently and rapidly. This scenario creates communication disruptions and proves to be a very challenging one. Meanwhile, with the introduction of new wireless broadband technologies such as WiMAX and 3GPP's Long Term Evolution Advanced (LTE-A), a heterogeneous wireless network environs have been created where it is possible to shift from one type of Radio Access Technology (RAT) to another different RAT. These new RATs provide a larger coverage and support higher mobility speeds to cater for user's demand for continuous and undisrupted services [1]. However, in order to achieve this target, an appropriate handover or path shifting scheme is needed.

There are many possibilities in achieving this feat. Several works have analyzed the outcomes of initiating handoff on different layers from physical layer through MAC layer, Network Layer, Transport layer and finally on the Application Layer [2-5]. According to [6] it was concluded that transport layer is the most suitable layer to execute a handover and on the Transport layer, one of the best options for a handover mechanism implementation is the Stream Control Transmission Protocol (SCTP) [7, 8]. SCTP have interesting features to provide better network performance. Features such as multi-homing and Heartbeat chunks can be manipulated to increase the efficiency of the handover or path switching process [9]. Using the multi-homing feature, a Mobile Node (MN) is assumed to be able to connect to two or more RAT simultaneously, thus creating several paths between the MN and its Corresponding Node (CN) in an SCTP association and using the heartbeat chunks, the quality of these paths can be monitored. The MN or CN is able to shift from one path to the other based on the quality of each path. However, to the best of our knowledge, most researches focus on the handover mechanism or process, and there is no relevant research which studies the switching between available paths when two or more paths are available between MN and CN. When a MN has several paths, according to the SCTP standard [7, 8], only one path will be chosen as the primary path, and unless that path deteriorates to a certain degree (reaching retransmission timeout (RTO) and etc.) it will stay on the same path regardless whether the quality of the current primary path is better or worse than other available paths. Hence, this article aims to tackle this issue with the following contributions:

- Propose an architecture in obtaining the required network parameters to be used as the decision criteria for path switching
- Propose and evaluate the optimal path selection mechanism which uses received signal strength indicator (RSSI) and the path delay as the decision metrics and implementing the Ant Colony Optimization (ACO) probabilistic equation in determining the optimal path.
- The results show that the proposed method is able help the MN to choose the optimal path and stay in the optimal path at a longer time before shifting to another path due to RSSI degradation when compared to previous methods.

The proposed mechanism is expected to be used in a heterogeneous network environment. However, initial design and simulations of the work are done in a homogeneous network context (wireless LAN (WLAN)), and only SCTP path switching is considered in this work. This paper is organized as follows; section 2 describes some of the important concepts to understand and appreciate the proposed idea and reviews the related works. The proposed mechanism is discussed in section 3. The evaluations are presented in

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section 4 and finally, section 5 concludes this work and discusses the future research direction.

II. RELEVANT CONCEPT AND RELATED WORK

This section discusses the important concepts in understanding the significance of the proposed mechanism and reviews some related work relevant to the proposed mechanism in this work.

1) *Relevant concept*

There are several types of handover available [10, 11]. Two of the most common methods are the hard handover (HHO) and the soft handover (SHO). In a HHO process, the MN will break its connection with the previous serving Base Station (BS) before connecting to the target BS, thus the term break-before-make. On the other hand, in SHO, the mobile node will connect to the target BS first before breaking its connection with the serving BS, thus the term make-before-break. In these two processes, the MN will naturally have to break its connection with the previous serving BS.

In a SCTP association, when considering a MN with multiple network interface card (NIC), it is assumed that it will be able to connect to two BSs, either both of the same RAT or different RAT. Hence, when multi-homing, the MN will be able to create different paths from itself towards the CN. Therefore, if the MN does not move out of the coverage of the previous BS's cell, it does not necessarily have to break its connection with that BS. So if the mobile node stays within the vicinity of two or more BSs, it will have a choice of path towards the CN with different path quality which will change from time to time. It will be a waste if the MN stays only at one path, when another available path could provide better service quality. Thus, the significance of this work should be clear at this point. Likewise, when the MN continuously keeps track on the changes in the path quality, it will automatically be on the right path (the path that will not deteriorate due to moving out of coverage cell), when it exits a BS's cell. Additionally, the handover disruption caused by path switching is theoretically nonexistent. Hence using the proposed mechanism will provide a seamless handover experience.

2) *Previous work*

In [4] and [5] a handover mechanism at the SCTP layer which uses RSSI value is discussed. The findings show that using RSSI value gives better performance for fast moving MN when compared to traditional network layer approaches. However, no mention of the effects of path delay was disclosed in these works. Due to the fact that this approach only uses RSSI value as the decision metric, it can be assumed that the proposed method will not react to the changes in the path delay due to congestion or other reasons.

Meanwhile, in [12] and [13] the handover decision is based on the International Telecommunication Union Technical Standards (ITU-T) simplified version of the Mean Opinion Score (MOS) which is mostly affected by the delay parameters (end-to-end (ETE) delay and jitter) of a path. Nevertheless, no mention of the effects of RSSI changes was discussed in these works. So it can be deducted that the proposed method will not react to the changes in the RSSI value.

In [14], a handover scheme which uses a chunk called Qos_Measurement_chunk which carries the radio information of the mobile node to be sent to the network. The work presented is done in an EGPRS environment, where the handover is done by the network. However, no specific parameter has been stated, and no method or architecture in obtaining the values from the Physical layer is stated.

ACO is an optimization method which is inspired by the foraging behavior of some ant species. As the ants move along a path, it will deposit a layer of chemical substance, which is called pheromone, to label the favorable path so that other ants from the same colony will be able to follow that path. In recent works [16], an implementation of this method has been done in a wireless sensor network environment which implements the ACO probabilistic equation (see equation (1)), and the outcome shows better results than previous methods. From this work, it can be seen that the ACO equation is a suitable tool for optimal path selection; it is also simple and scalable. The general form of this equation is as shown in equation (1)

Study in [9] proposed to use RSSI and path delay as the decision metric in finding the optimal path among the available path in a SCTP association. Using this approach, the MN can obtain the value of RSSI from the Physical layer and decide the optimal path by implementing the ACO and the two parameters (RSSI and path delay). However, the work in [9] has not thoroughly evaluated the effectiveness of the proposed approach. Thus, the summary and some modifications of the proposed method will be discussed in the following section, and the evaluations will be discussed in section 4.

III. THE PROPOSED OPTIMAL PATH SELECTION MECHANISM

In this work, two parameters, which are the RSSI and ETE delay (path delay), are used as the decision metrics, and the ACO probabilistic equation is used as the optimal path selector. The general form of the equation is as in equation (1) [16]. P_{ij}^k is the probability of choosing a path; τ is the path delay factor; η is the first heuristic value and ω is the second heuristic value. The number of heuristic values used can be adapted according to the research needs. α, β and γ are the parameters that control the relative weight of the delay and the heuristic values, and the sum of these three parameters is equal to 1.

$$P_{ij}^k = \frac{\tau^\alpha \eta^\beta \omega^\gamma}{\sum_{h \in j_i^k} \left(\tau^\alpha \eta^\beta \omega^\gamma\right)} \tag{1}$$

Heartbeat chunks are used to obtain the ETE delay. When a Heartbeat chunk is deployed, it carries the timestamp of that chunk, and when the sender receives a Heartbeat Acknowledgment from its peer, the round trip ETE delay will be acquired. From this value, the delay metric will be attained using the following rule:

$$\tau = \begin{cases} \dfrac{ETE_{\max} - ETE}{ETE_{\max}} & \left(ETE < ETE_{\max}\right) \\ 0 & \left(ETE \geq ETE_{\max}\right) \end{cases} \tag{2}$$

ETE_{max} is the maximum allowable disruption time. According to [13], the acceptable one way delay which will not affect the interactivity or quality of a VoIP call is 150ms and below.

Consequently, ETE_{max} is set to two times 150ms (which is 300ms) to accommodate for round trip ETE delay. So according to rule in (2), when ETE is smaller than ETE_{max}, the delay metric, τ, will be calculated using the provided equation, whilst when ETE is larger than ETE_{max}, τ will be set to 0.

Meanwhile, the value of the RSSI is directly obtained from the Physical layer. In order to get the needed information from the Physical layer, a cross-layer architecture is proposed (see figure 1). The value used in the ACO probabilistic equation is the normalized value of the RSSI, η, as shown in equation (3). The $RSSI_{MN}$ is the RSSI of the Access Point (AP) related to the SCTP path measured by the MN, and $RSSI_{max}$ is the maximum value of RSSI.

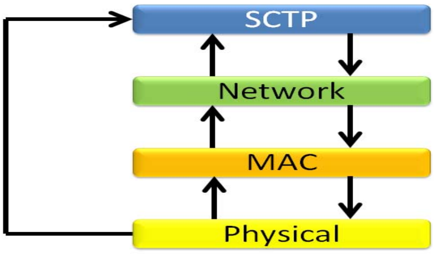

Figure 1. The Cross Layer Architecture

$$\eta = \frac{RSSI_{MN}}{RSSI_{\max}} \tag{3}$$

With the combination of these two parameters, the adapted ACO probabilistic equation will become as follows:

$$P_{ij}^{k} = \frac{\tau^{0.5}\eta^{0.5}}{\sum_{h\in j_i^k}\left(\tau^{0.5}\eta^{0.5}\right)} \tag{4}$$

P_{ij}^{k} is the probability of choosing a path; τ and η are the delay metric and RSSI metric (heuristic value) respectively, as discussed previously. The indices of both parameters in equation (4) are set to 0.5 to give fairness to both parameters. In this equation, only one heuristic value is used.

Another important parameter which is considered in this work is the RSSI value of the CN. By obtaining this information, the MN can know the coverage or signal quality of the CN in a scenario where the CN is connected wirelessly to the BS and it has no other wired connections to the network. In an instance where the primary address of the CN degrades due to the CN moving or some failures at the BS's side, the MN will be able to react accordingly by changing its primary address. This could reduce the service disruptions because the MN will not have to wait for several RTOs before executing primary path change. The value used in the ACO probabilistic equation, ω, is as shown in equation (5), where $RSSI_{CN}$ is the RSSI of the Access Point (AP) related to the SCTP path measured by the CN. Moreover, in order for the MN to be able to attain the values of RSSI at the CN, a new heartbeat chunk parameter is proposed. In this parameter, the value of RSSI of the sender will be inserted, so that both nodes (MN and CN) can exchange RSSI information between themselves. The proposed parameter is shown as in figure 2. After adding this parameter, the adapted equation will be as in equation (6), where ω is the second heuristic value. The indices of all parameters are set to 1/3 to give fairness to all parameters.

IV. Evaluations

This section evaluates the reaction of the proposed approach. Three types of assessment were considered in order to evaluate the proposed mechanism. The first evaluation is done to evaluate the reaction of the mechanism to the changes in the SCTP path quality. The second evaluation is done in order to evaluate the mechanism's reaction when the MN is moving at constant speed. Both first and second evaluation was done using the adapted ACO equation with two parameters as in equation (4). The third evaluation is done to see the outcome when the third parameter is included as in equation (6). The simulations for the evaluations were conducted using the INETMANET module in OMNeT++ version 4.1 [15].

$$\omega = \frac{RSSI_{CN}}{RSSI_{\max}} \tag{5}$$

$$P_{ij}^{k} = \frac{\tau^{1/3}\eta^{1/3}\omega^{1/3}}{\sum_{h\in j_i^k}\left(\tau^{1/3}\eta^{1/3}\omega^{1/3}\right)} \tag{6}$$

Type = 0x04	*Chunk flags = 0*	*Chunk length = variable*
Heartbeat Parameter type = 1		*Heartbeat info Length = variable*
Heartbeat sender specific information		
Heartbeat parameter type = 2		*Heartbeat info length = variable*
Heartbeat sender RSSI value		

Figure 2. Proposed heartbeat chunk parameter

Before moving to the evaluations, some clarification on the meaning of optimal path and the assumptions considered in this work should be discussed. Having only the highest RSSI or the shortest path delay does not mean that the path is optimal. An optimal path should have an acceptable link quality (path delay is not larger than the allowable disruption time) and is not susceptible to out of bound connection loss (due to RSSI degradation). For the assumptions, consider figure 3. It is assumed that all network registrations have been completed and the MN is connected to cells 1 and 2, whilst CN is connected to cells 3 and 4. Two paths are created in the SCTP association where path 1 is the AP1-AP3 pair, whilst path 2 is the AP2-AP4 pair.

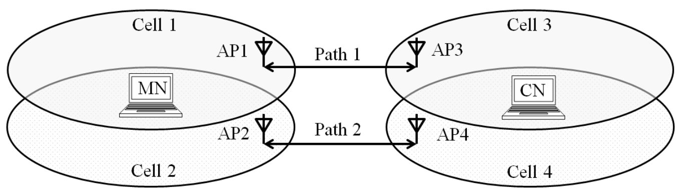

Figure 3. Network Scenario

1) *The first evaluation*

In the first evaluation, both the MN and CN are programmed to be static. The transmission power of AP1 was varied from 2mW to 30mW, whilst other APs are set to 2mW. Besides that, the path delay of Path 1 is varied from 0ms towards 150ms, whilst the path delay of Path 2 is set to 0ms. In the simulation, the received signal strength is measured by using the following equation:

$$P_{rx} = \frac{P_{tx}\lambda^2}{16\pi^2 d^2} \tag{7}$$

P_{rx} is the received power; P_{tx} is the transmission power of the AP; λ is the wavelength and d is the distance between the transmitter and receiver. The outcome is shown in figures 4, 5 and 6. In the results, the received signal is converted to dBm. In the graphs, the z-axis is the probability of MN choosing path 1. Because there were only two paths considered in this work, when the probability is above 0.5, MN will choose path 1 as the optimal path, and when the probability is below 0.5, path 2 will be chosen. The range of y-axis, which is the path delay, is set from 0ms to 150ms because this range is within the allowable disruption time as discussed in section 3. Meanwhile, the lowest value in the x-axis is -80 dBm because in the simulation, the sensitivity of the receiving antenna is -85 dBm; hence, if the received signal is below than that, the MN and CN will lose its connection to the AP. In obtaining the graph in figures 4 and 5, the proposed mechanism is modified so that it uses only RSSI and only path delay respectively. The outcome of figure 4 and figure 5 is obvious because in figure 4, the mechanism only uses RSSI value as the decision criterion, hence there are only changes in the path probability corrsponding to the changes in the RSSI value, whilst in figure 5, the mechanism only reacts to the changes in path delay due to the fact that the delay metric is the only criterion used.

Meanwhile in figure 6, it can be seen that the proposed mechanism which uses both RSSI and path delay as the decision criteria shows that the path probability determined by the adapted ACO equation corresponds to the changes of those

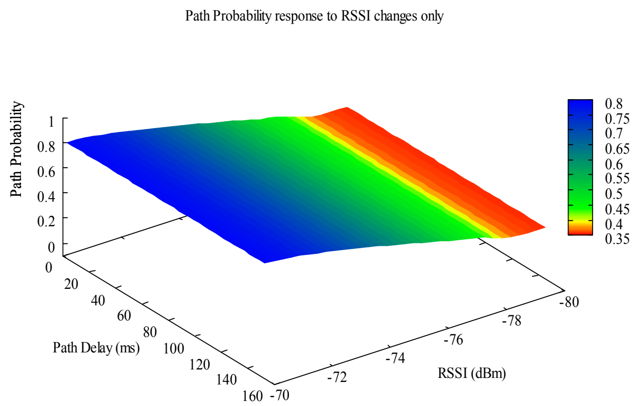

Figure 4. Using RSSI only

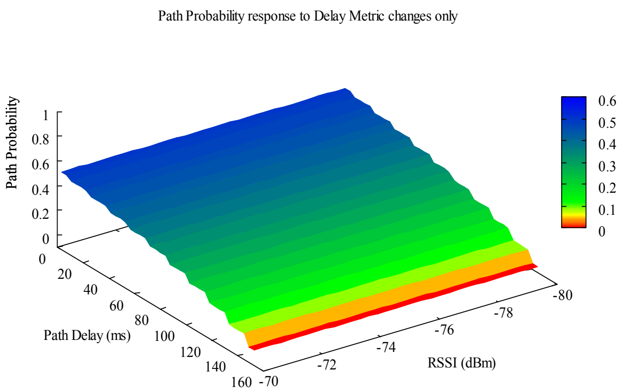

Figure 5. Using path delay only

two parameters. It can be concluded here that the proposed method is beneficial to both scenario where the MN stays in the vicinity of the same AP as well as when MN moves from one cell to another, because when it stays, it can detect the path degradation due to the path delay, and when it moves, it will detect the degradation of the RSSI.

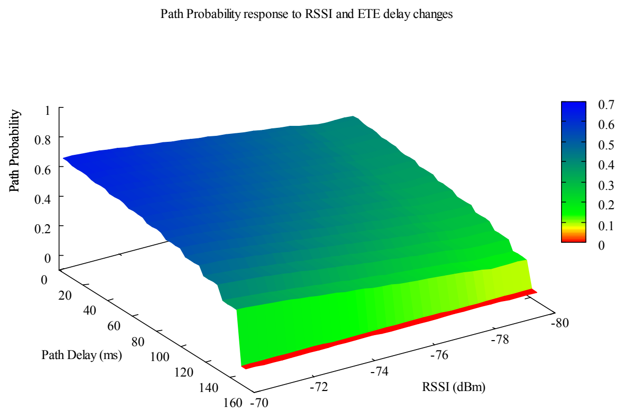

Figure 6. Using both parameters (equation (4))

2) Second Evaluation

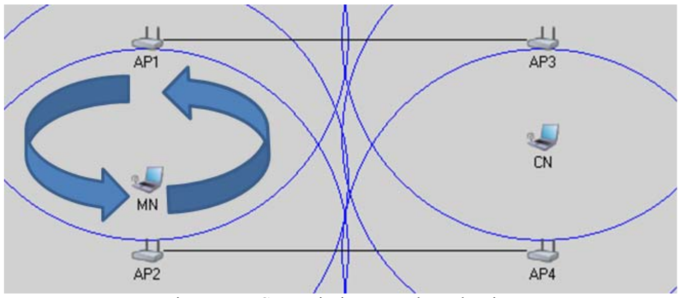

Figure 7. Scenario in second Evaluation

In the second evaluation, the mobile node is programmed to move in a circular motion as in figure 7 at various velocities (2m/s to 10 m/s). Transmission power of all APs is set to 2mW. The path delay of path 1 is varied from 0ms to 150ms whereas the path delay of path 2 is set to 0ms. Figure 8 shows the RSSI changes of AP1 when MN is moving at different speeds. In figure 9, we can see that when the mechanism only uses RSSI as the decision metrics, the path probability pattern directly corresponds to the change in RSSI value. In contrast, when the mechanism uses only Delay Metric, the outcome is as in figure 10 for all velocity. This is due to the fact that when only delay metric is used, the mechanism will not react to any RSSI changes. Figure 11 shows the outcome when both parameters are used. When the path delay is equal to 0ms, the outcome is nearly the same as the using RSSI only. But when the path delay increases, the graph seems to be shifting downward, meaning that the time when MN will choose path 2 will increase. For a better understanding, refer figure 12. In this figure, the outcome of all three situations (RSSI only, path delay only and using both parameters) when the network parameter is the same (velocity = 8m/s; path 1 delay = 120ms; path 2 delay = 0ms). Take note that when using the proposed method, the MN will try to stay at path 2 at a longer time (81% of the time) compared to the time it chooses path 1. Notice that the path delay of path 2 is 0ms which is better than the path delay on path 1 which is 120ms. So, intuitively, if the MN stays at path 2 at a longer time, its link quality should be better. From this evaluation, it can be concluded that the

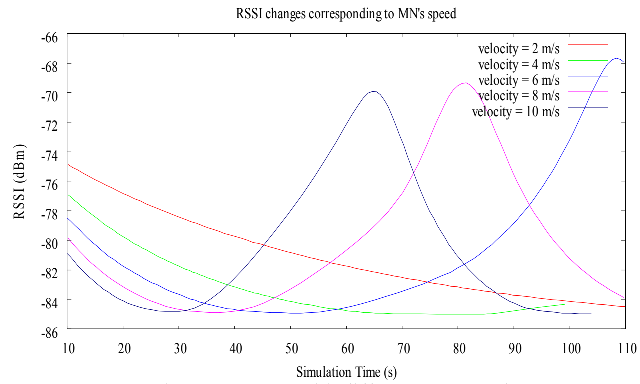

Figure 8. RSSI with different MN speed

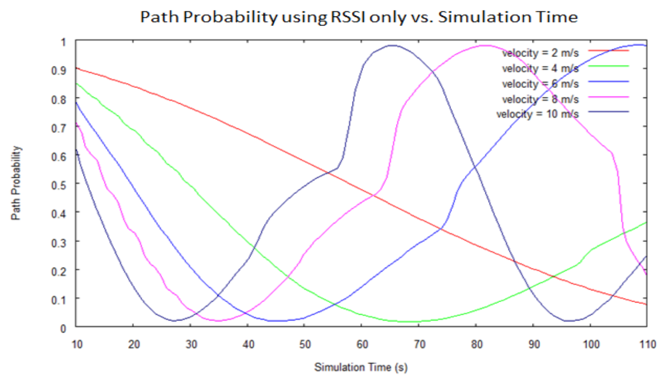

Figure 9. Path probability using RSSI only

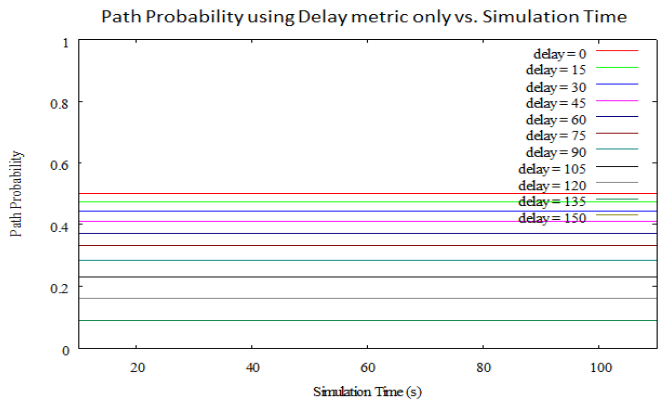

Figure 10. Path Probability using Delay Metric only

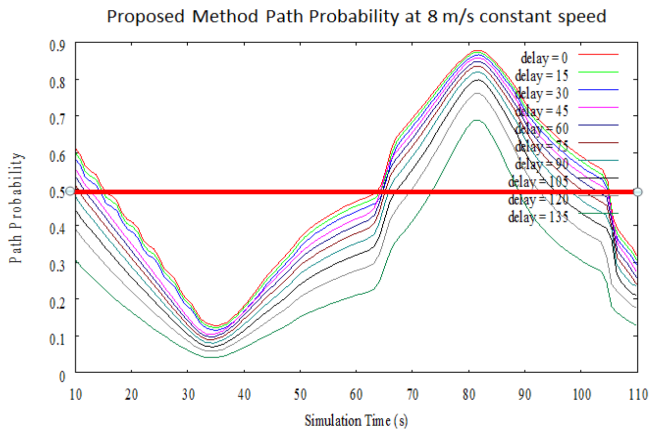

Figure 11. Path Probability using both decision metrics (equation (3))

proposed mechanism will try to let the MN stay at the path which has better link quality as long as possible before shifting to a path with an acceptable link quality due to RSSI degradation.

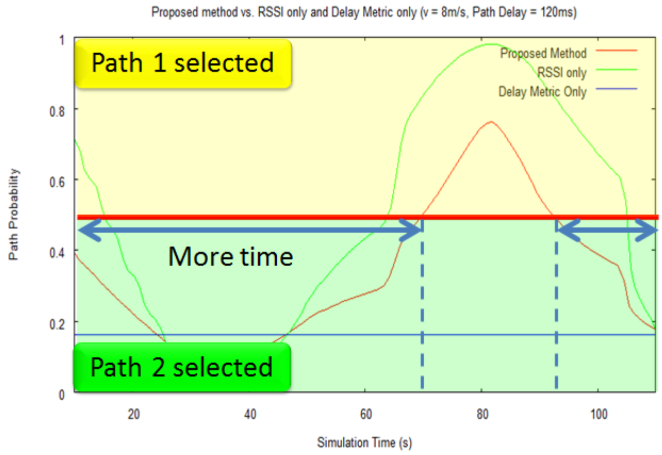

Figure 12. Comparison between proposed method and previous methods

3) *Third Evaluation*

In the third evaluation, a third parameter (the RSSI at the CN) is considered. The network condition is similar to the one in the second evaluation, except that the path delay of path 2 is set to 20ms and the position of CN is varied so that there are changes in the RSSI value at the CN. It can be seen that the results are similar to the second evaluation; when the RSSI level of the CN is high, the MN will try to stay on path 1 at a longer time, and as the RSSI level of CN degrades, the time where the proposed mechanism chooses Path 1 becomes shorter compared to when using 2 parameters, or RSSI only (see figure 13).

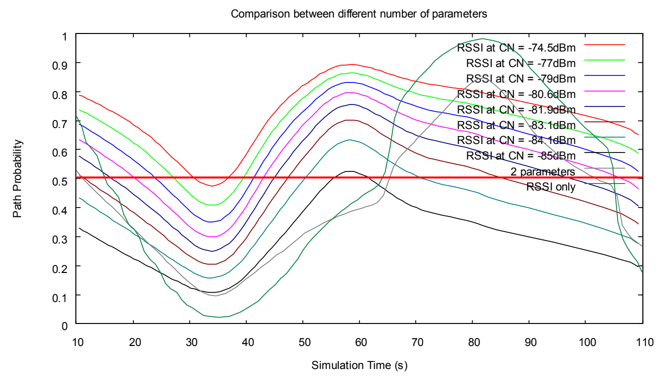

Figure 13. Comparison between using 3 parameters and 2 parameters and RSSI only

V. CONCLUSION AND FUTURE WORK

This research thoroughly studies the reaction of the proposed mechanism towards the changes in path delay and RSSI level at the MN as well as the CN. The results show that the mechanism is able to select the optimal path (according to the definition proposed) for the MN. The results from this work can benefit both wireless and wired networks. In future research, other parameters which affect the link quality will be considered.

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