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Exploiting Distance Information for Transparent Access Point Driven Wi-Fi Handovers

Ensar Zeljković*, Roberto Riggio†, Steven Latré*,

* University of Antwerp - imec,
IDLab research group
Middelheimlaan 1, 2020 Antwerp, Belgium
E-mail: ensar.zeljkovic@uantwerpen.be, steven.latre@uantwerpen.be

† FBK CREATE-NET,
Future Networks Research Unit
Via Alla Cascata 56, 38123 Trento, Italy
E-mail: rriggio@fbk.eu

***Abstract*—IEEE 802.11 (Wi-Fi) networks' popularity has boomed in recent years and their presence is continuously increasing. More and more large-scale networks are being deployed, consisting of a large number of access points. In these networks, the handover process has proven to be very challenging. In standard Wi-Fi, the client is responsible for making the handover decision and the access point plays no role in it. This can lead to several issues such as short stays, oscillating behaviour and poor overall connectivity. In this paper, we propose a way to shift the handover process from client to access point, without requiring any modification to the client itself. By using network virtualization, we are able to perform proactive and transparent handovers, steered by a centralized controller. This allows us to exploit valuable information such as the clients' distance from all available access points, leading to a better handover process. In this paper, we present several distance aware handover algorithms. The results show that we are able to improve the handover algorithm using this information by reducing the number of handovers and avoiding unnecessary ones. We were able to reduce the throughput penalty during a handover by 50% which leads to a more seamless handover process.**

I. Introduction

IEEE 802.11 networks or Wi-Fi [1], have boomed in recent years with an ever increasing presence. As pointed out by Mishra et al., a crucial process in Wi-Fi is the handover [2]. A handover is a process that occurs when a user moves its association from one Access Point (AP) to another. This can be a result of the user leaving the coverage range of its current AP and moving to another. In this case, the wireless connection will start to deteriorate, which can be observed through the Received Signal Strength Indicator (RSSI). Eventually, the RSSI will drop to a point where the user will disconnect from the current AP. In order to maintain connectivity, the user has to switch its association to another AP [3].

In Wi-Fi, the entire decision is made by the user. While the actual handover algorithm is often proprietary, all handover algorithms consist of three steps: Discovery, authentication and association. During the Discovery phase, the Client actively or passively scans all the available channels in order to find available AP in its vicinity. During the other two phases, there is a exchange of several management frames to associate the user to the new AP. All this induces latency. As pointed out by Tseng et al. and Wisniewski et al., the Discovery phase is the most time consuming phase [4], [5]. In general, the whole handover process can easily take up to 2 seconds, but the actual induced delay is very variable. As no user traffic is exchanged between the user and AP it often leads to considerable Quality of Service (QoS) disruptions. Mishra et al. have also concluded that the latency induced by a handover varies from one handover to another, but also varies among AP and user equipment from different vendors as the algorithm itself is proprietary [2]. Also, the handovers are client driven so the AP plays no role in it. This can lead to several issues such as short stays, oscillating behaviour and poor overall connectivity.

In this paper, we propose a virtualization-based approach to move the decision process from the user to the access points. High level programming abstractions are used for managing wireless networks, one of which is an interface for wireless clients state management and acts like a per-client AP. Simply by assigned the client to another AP effectively does a handover. This handover is done from a centralized controller, therefore it's AP based and seamless. We present several access-point driven handovers in Wi-Fi, which transparently move the handover decision from user to access point without requiring any modification to existing clients.

The contributions of this paper are three-fold. First, based on a software defined wireless network virtualization framework, called 5G-EmPOWER, we present a way to create transparent and seamless handovers. Second and third, building on top of that we introduce two advanced handover algorithms that use RSSI as an estimation of the user distance to the available access points to steer the handover process. The first one is the Node based distance estimation algorithm that uses distance information to estimate the location of the user. Using the RSSI value the distance can be estimated and used to decide to which AP the user should be handed over to. The second one is the Region based distance estimation algorithm. In this algorithm, we create regions which are groups of APs. The decision is again distance based, but now in regards to the regions and not individual nodes. To the best of our knowledge, this work is the first that exploits distance information to limit the number of unnecessary handovers in a way that is transparent to the end user.

The structure of the paper is as follows. Section II gives an overview of related work. Section III introduces the Software Defined Networking (SDN) based Wi-Fi management using 5G-EmPOWER. It explains in short what 5G-EmPOWER does and what abstractions are used for this paper. Following this, Section IV describes in detail the AP driven handovers that exploit distance information. Here, the algorithms are divided into two categories, the Distance based and Region based algorithms. Section V is the performance evaluation section. The experimental setup is described and the results of testing the algorithms are presented. Finally, Section VI gives the conclusions of this paper and future work.

II. Related work

The domain of handovers is a very vibrant research domain, focusing mainly on attempting to reduce the handover delay. In this section we will give a short overview of the research done in this field.

Croitoru et al. propose that the client should connect to all the APs that it can detect and then split the traffic over them [6]. To do so, they have implemented the MultiPath Transmission Control Protocol (MPTCP) protocol. Using MPTCP the client is able to send traffic over multiple APs. There experimentation has shown that this approach can enhance the capacity and reliability of the Transmission Control Protocol (TCP) connection, but the scalability of the proposed solution is in question. Also, connecting to multiple APs means decreasing the throughput when a lot of client do the same thing.

One approach to the problem seemed to attract quite a few researchers. The approach consists of creating a Neighbour graph or list. Kim et al. propose a selective scanning method during a handover through which the client can create a Neighbour graph of potential APs [7]. The drawback of this solution is that the graph can only be created during a handover. Ramani et al. propose a similar approach called SyncScan [8]. SyncScan uses passive scanning to discover the neighbouring APs. In order for the algorithm to work, the client and the APs have to be synchronized, which increases the complexity of the proposed approach. On the other hand, Singh et al. propose active scanning to discover the neighbouring APs [9]. Of course, this results in more traffic. Merz proposes creating an ordered list of APs [10]. The client then associates to the APs in this list in a predefined order. This means that the client has move along a predefined path. Even though this approach decreases the discovery time to a minimum, in lacks flexibility because the client has to strictly follow a predefined path. All these approaches create the Neighbour graph or list to minimize the discovery phase of the handover process, which induces the highest latency. Also, these approaches require the modification of the end user.

There has also been research in using location information of the client to create a smarter handover decision. Manodham et al. propose an approach where the APs use two transceivers, one for data and one to scan for clients in its coverage area [11]. Then, the RSSI or Time Difference of Arrival (TDoA) techniques are used to estimate the clients location. Obviously, there has to be time synchronization in order for this to work, which leads to additional complexity. Also, the APs exchange data and localize the client in parallel, which can lead to a contradiction during radio planning. Another similar approach is proposed by Wisniewki et al, where the central system knows the location of the APs and then looks at the location of the client [5]. The location of the client is obtained using the Time Difference of Arrival (TDoA) technique. The handover is triggered when the system calculates that there should be a handover and signals the client to do a handover. This approach is still client based and needs a way for the system to communicate to the client and also there has to be strict synchronization for the TDoA technique to work. Tseng et al. also propose a location based handover algorithm to reduce the handover overhead [4]. In their approach the client can detect the AP that it is most likely going towards to using its current location and AP topology information stored in a central server. The server also stores the parameters for the association to a particular AP. This way the client can associate to the AP without a probe beforehand. The location of the client is determined by Global Positioning System (GPS). Again the handover is client based and there needs to be a modification of the client to be able to communicate to the central server. Also, using GPS as a localization technique can be limiting indoors.

Finally, there has been intensive research in the vertical handover domain. Even though this paper analyses the horizontal handovers, there are some useful insights into the handover problem in the vertical handover domain. Naeem et al. analyze the handover problem between Wi-Fi and Worldwide Interoperability for Microwave Access (WiMAX) networks [12]. They propose a decision-making algorithm for a handover based on the RSSI value and end-to-end TCP latency. Using this information, they create a radius boundary inside which the handover must take place to be seamless. Their simulations have confirmed that this boundary depends on the end-to-end TCP latency and the speed the client is moving towards to or away from the AP. They also concluded that additional information from the network layer are needed for an optimal handover solution. Tsuboi et al. also look at the vertical handover between Wi-Fi and WiMAX [13]. Their approach is to use a location aware fast handover technique that targets to minimize network detection delay, select proper target network for handover and eliminate Ping-Pong effect. Inzerilli et al. look into the vertical handovers between Universal Mobile Telecommunications System (UMTS) and Wi-Fi [14]. Their approach uses the location information and throughput to decide when a vertical handover should occur between these networks.

III. SDN-BASED HANDOVER MANAGEMENT

As previously discussed, in standard Wi-Fi, the client is responsible for carrying out the handover decision. While there are obvious reasons for moving this decision to a centralized controller, it is unrealistic to assume that, in the near future, this can be achieved by changing the IEEE 802.11 protocol itself of the vast variety of already existing devices. Instead, we take a different approach, where we trick the client in handing over the decision power to a centralized client. This is done using an SDN-based framework, called 5G-EmPower, which introduces reusable high-level programming abstractions for managing wireless networks and which has been presented in previous work by Riggio et al. [15]. 5G-EmPOWER implements a Software Defined Radio Access Network (SD-RAN) Controller that realizes the abstractions and a Software Development Kit (SDK) which allows us to create and deploy new applications and services as Network Apps on top of it.

The AP in a RAN is referred to as a Wireless Termination Point (WTP) and it provides the clients with wireless connectivity. These WTPs communicate to the SD-RAN Controller through a secure channel. The SD-RAN Controller runs Virtual networks or Virtual slices on top of the physical infrastructure. So, a virtual slice consists of a set of available WTPs. The Network apps run on top of the Controller and run on a specific virtual slice. The Controller ensures that the Network app only sees the resources available in that specific network slice. These Network apps use the REST or native Python Application Programming Interface (API) in order to exploit the programming primitives.

There are three abstractions which are particularly important for enabling seamless handovers: (i) Light Virtual Access Point (LVAP), (ii) the Resource Pool and (iii) Channel Quality and interference Map (CQM). The LVAP is a high level interface for wireless clients state management. This interface handles all the technology-dependent details, like association, authentication, etc. When a wireless client wants to join the network, a new LVAP will be specifically created for that client. So, in essence, the LVAP is a per-client virtual AP which simplifies the network management and introduces seamless mobility. Each WTP will, therefore, host as many LVAPs as there are clients that are currently under its control.

The Resource Pool is the abstraction of network resources. It consists of Resource Blocks that are identified by a frequency band, time interval and the WTP at which it is available. For example, a Resource block at a particular WTP can be $((36, HT40), \infty)$. This means that the WTP is an AP tuned on channel 36 and uses 40MHz wide channels. These Resource blocks are then assigned to LVAPs.

The CQM abstraction provides a full view of the network state in terms of channel quality between LVAPs and WTPs over the available Resource Blocks. For this, RSSI measurement is used at each WTP. So, by using this abstraction, we can get the RSSI measurement for a particular LVAP from each WTP. Using these abstractions a handover is accomplished by simply assigning a particular LVAP to a new Resource Block. Moreover, the handover is AP driven and not client driven.

IV. HANDOVER ALGORITHMS

The SDN-based approach explained above provides the enabling technology to provide seamless handovers. However, there is still a need for actual centralized handover algorithms. In this section, we propose two algorithms that estimate the user's distance from the various WTP. Moreover, we also present a simple RSSI maximizing algorithm for the sake of benchmarking. These algorithms are created as Network Apps in 5G-EmPOWER. Each algorithm monitors the RSSI between client and WTP and stores it centrally on the controller. In both distance-based algorithms, the RSSI is used as the metric to estimate the distance of the user from each WTP.

A. Naive handover algorithm

For the sake of benchmarking the distance-based algorithms, we first present a naive centralized handover algorithm. As the name suggests, this algorithm simply detects the RSSI value between each WTP and the user using the User Channel Quality Map (UCQM) API. The controller collects all the information from a WTP: the LVAPs, their RSSI values from that particular WTP and their active flags which indicate whether they are currently using a Resource block on that WTP. The LVAPs are handed over to the WTP with the current highest RSSI value.

B. Distance based handover algorithms

This section introduces two distance based handover algorithms: (i) Node based distance estimation and (ii) Region based distance estimation algorithms. These algorithms first estimate the distance of the user from WTPs and then use this information to create a decision making score variable which decides to which WTP should the user be handed over to.

1) Node based distance estimation: This algorithm looks at the historical evolution of the RSSI over time and calculates a score based on this. First, it smooths the RSSI value using a sliding window. A window consists of multiple RSSI values, obtained at regular time intervals, so $(RSSI_{t1}, RSSI_{t2}, ..., RSSI_{t_n})$. The window length is determined by the $NUMBER\_OF\_RSSI\_VALUES$ variable. Once the required length is reached, the average RSSI in that window is calculated. To smoothen the RSSI even more, the maximum and minimum RSSI values in a particular window are not taken into account. So the average RSSI is calculated based on Equation (1). This way the RSSI peaks are discarded from the calculation and a more accurate average RSSI is determined.

$$A_{RSSI}(t) = \frac{\sum_i RSSI_i - MAX_{RSSI} - MIN_{RSSI}}{NUMBER\_OF\_RSSI\_VALUES - 2} \quad (1)$$

Once the algorithm has a current average RSSI, the score variable is calculated using Equation (2).

$$Score_i = Score_{i-1} + (A_{RSSI}(t) - A_{RSSI}(t-1)) \quad (2)$$

The score should be interpreted as follows: if the difference between $A_{RSSI}(t)$ and $A_{RSSI}(t-1)$ is negative, then that means the RSSI is getting worse or the user is getting further away from a particular WTP. If that happens, the score variable decreases to account for that behavior. On the other hand, if the difference is positive, the score increases to represent the user moving closer to a particular WTP. Also, the bigger the difference between these values, the more the user is moving towards or away from the WTP. This way, the score variable can be used to estimate the users location and it is used to decide to which WTP the user should be handed over to. The algorithm waits for the RSSI value of the currently associated WTP to drop below the $RSSI\_LIMIT$ and then triggers a handover to the WTP with the highest current score.

2) Region based distance estimation: The final algorithm for this paper is an enhancement of the previous one to include regions. A region is a group of WTPs that are close to each other. The calculations of the average RSSI and the score from the previous algorithm now apply to regions. The average RSSI and score variable are also still calculated for the individual WTPs in regions.

The controller collects the same data as in the previous algorithm. Additional data about Regions is stored: the WTPs that are part of the region and the average RSSI and score variables. Again, the $RSSI\_LIMIT$ threshold is introduced. At regular intervals, the average RSSI and score variables are calculated. If the RSSI of the LVAP drops below the $RSSI\_LIMIT$ threshold, a handover is triggered. First, the region with the highest score is selected. Next, a WTP with the highest individual score in that region is selected and the user is handed over to that WTP.

V. Performance evaluation

A. Experimental setup

In order to analyze handovers in Wi-Fi, a test environment has been created using 5G-EmPOWER [16]. The 5G-EmPOWER framework consists of one SD-RAN Controller and three WTPs. The WTPs have access to the Internet through a local router. Using the 5G-EmPOWER SD-RAN Controller, a Virtual slice was created and all three WTPs were assigned to that Virtual slice. The setup can be seen on Figure 1. As can be seen from figure 1, the distance between (WTP-3, WTP-4) is larger than (WTP-3, WTP-2). The scenario consist of a user moving from the area of WTP-2 to the area of WTP-4 and back. The prediction is that the user will be handed over from WTP-2 to WTP-3 as it moves away from WTP-2. Continuing to WTP-4, the user will be handed over from WTP-3 to WTP-4.

The goal of this paper is to exploit the distance information in order to create AP driven handover algorithms. These algorithms should be able to detect that the user is moving towards WTP-4, and skip the unnecessary handover to WTP-3 in between. Of course, the assumption is that the distance between WTP-2 and WTP-4 is not too big, because the RSSI value would drop far too low and the network would become useless.

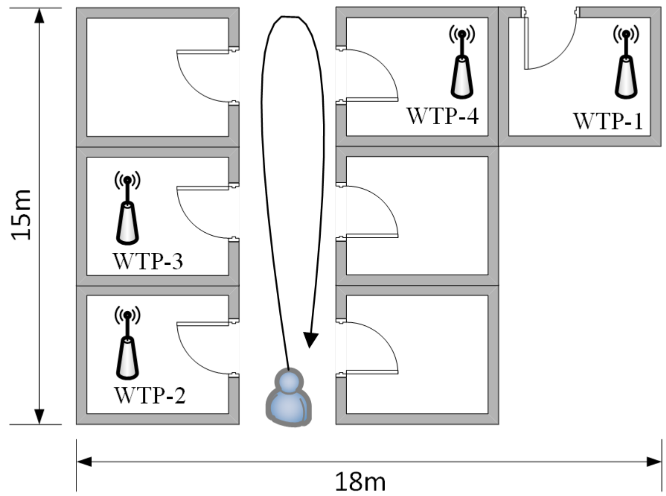

Fig. 1. 5G-EmPOWER Test Environment Network

The test setup has been deployed in a campus building at the University of Antwerp. The three WTPs were installed in offices on the same floor. This is not a controlled environment, as it has other Wi-Fi networks in range that are used at the campus. This will give an insight to real world applications of such handover algorithms.

As performance metrics, we measure the client's association to a particular WTP and the corresponding throughput penalty during the handover. The throughput penalty is calculated by sending a constant 5Mbps stream from user to a server on the Internet. The handover process will typically trigger a drop in this throughput and, obviously, the goal is to minimize this drop as much as possible. The $RSSI\_LIMIT$ threshold is set to $-70dBm$, while the update period is set to $500ms$. The ω parameter in the Weighted Normalized Difference in RSSI algorithm is set to 0.1, to put less weight on the current RSSI value. For the Difference in Average RSSI using Sliding Window and its optimized version, the $NUMBER\_OF\_RSSI\_VALUES$ variable is set to 5. As for the Region based algorithm, an additional WTP was introduced in the network to create a Region. This is the WTP-1 device that is put after the WTP-4, but close to it, in order to create a Region, Region 1. WTP-3 is part of Region-2, and WTP-2 is in Region-3.

B. Results description

In this section, we will discuss the results of the experiments. The results are analyzed in two directions: (i) user association and (ii) throughput.

1) User association: Figures 2, 3 and 4 show the RSSI value of the user regarding all of the WTPs, the score variable that is used to decide to which WTP should the user be handed over to and the association graph which shows which WTP is the user currently associated to. The RSSI graphs show the evolution of the RSSI as the user is moving from WTP-2, walks past WTP-3, goes towards WTP-4 and then walks back to WTP-2. For the region based distance estimation algorithm there is an introduction of one more WTP, the WTP-1. The

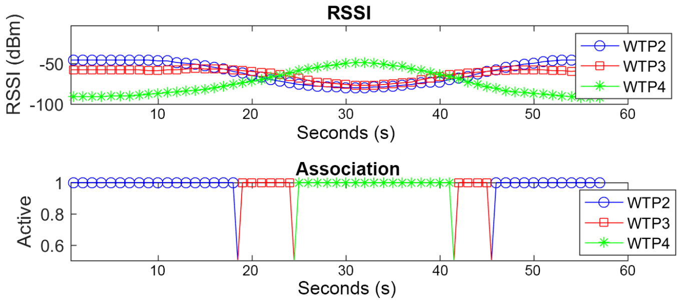

Fig. 2. RSSI and user association graphs in the naive algorithm

score variable graphs are present only for the node and region based algorithms, since the naive handover algorithm uses RSSI for decision making.

The association graphs show the current association of the user regarding the WTPs. For the naive handover algorithm, as the user starts from the area covered by WTP-2, the user is first connected to that WTP. After moving closer to WTP-3, the RSSI value of WTP-3 begins to rise and eventually surpasses the RSSI of WTP-2. As soon as this happens, the user is handed over to WTP-3. Moving further, the user gets closer to WTP-4 and once its RSSI is the highest it is handed over to WTP-4. When the user walks back from WTP-4 to WTP-2, the same happens in reverse order. We can observe that the user is associated to WTP-3 for a short period of time and could benefit from associating straight away to WTP-4. This way we would avoid the unnecessary handover and limit the number of handovers in general.

Looking at the association graphs of the node and region based distance estimation algorithms on Figures 3 and 4, we see that the user is handed over from WTP-2 straight to WTP-4 when moving towards WTP-4 and also from WTP-4 to WTP-2 when moving back to WTP-2, effectively avoiding the unnecessary handover to WTP-3. When looking at the score graphs for these algorithms, we see that the score variable of WTP-4 starts rising higher then the one for WTP-3, as the

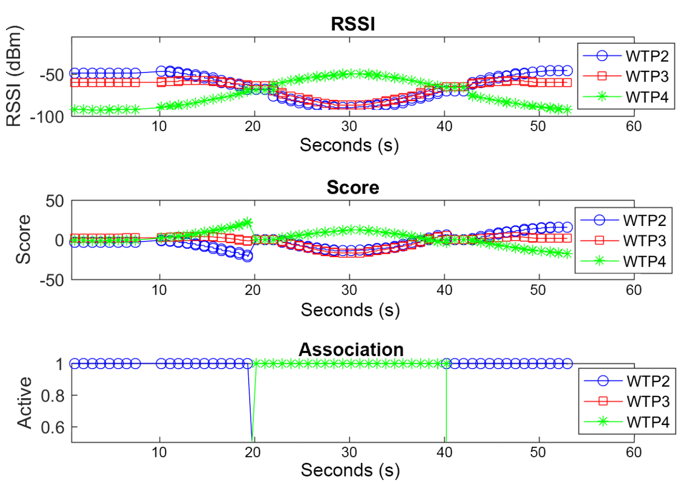

Fig. 3. RSSI, decision making Score variable and user association graphs in the Node based algorithm

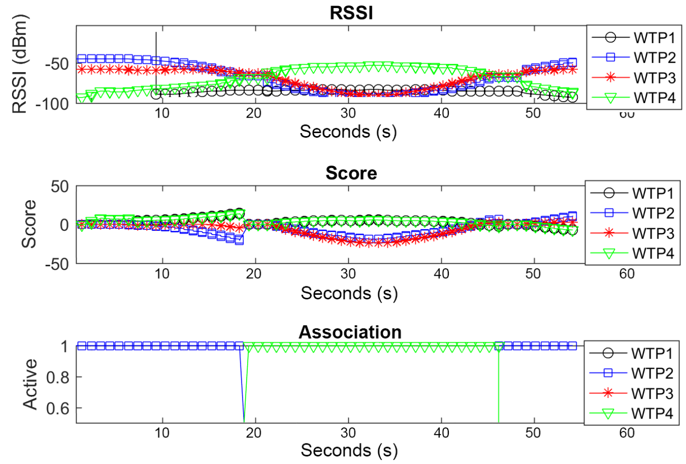

Fig. 4. RSSI, decision making Score variable and user association graphs in the Region based algorithm

RSSI for WTP-4 starts rising in higher increments then the RSSI of WTP-3. The RSSI of WTP-3 is steadily rising and then starts decreasing as the user passes by it and moves to the coverage area of WTP-4. This is represented through the score variable. In this way the algorithm can detect that the user is moving towards WTP-4 and hands the user immediately to that WTP. The same principle applies when the user moves back from WTP-4 to WTP-2.

The node and region based distance estimation handover algorithms show similar results when it comes to user association. A slight difference can be observed in the score variable graph, where we see that the score variable doesn't have a steep climb, which is a consequence of the presence of WTP-1 with a low RSSI. The score of region-1 is calculated based on the scores of WTP-1 and WTP-4. But even with the low RSSI from WTP-1, the algorithm still hands over the user to WTP-4. The score for region-1 is the highest, so that region is selected. From within the region, WTP-4 has the better individual score variable, so the user is handed over to that WTP.

2) Throughput: Figure 5 shows the throughput of the user when using the naive and distance based algorithms. We

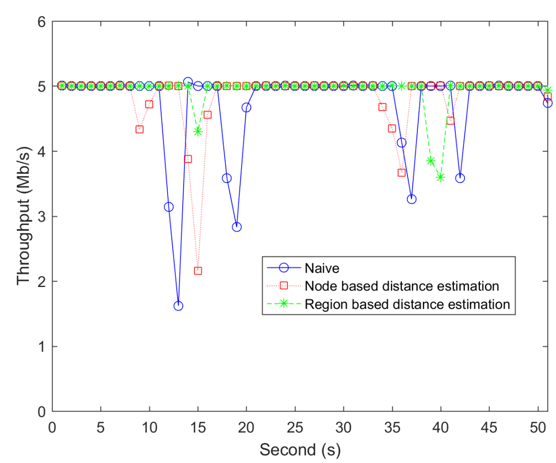

Fig. 5. Throughput of all three algorithms

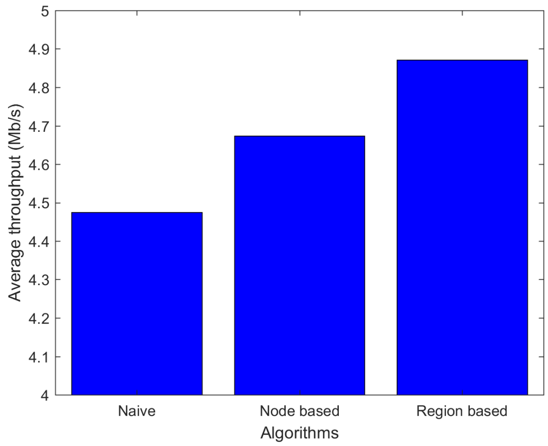

Fig. 6. Average throughput of all three algorithms during the handover process

can clearly see a slight and short drop in throughput when the handovers occur, but not a complete drop to zero. The naive algorithm experienced the biggest drop in throughput, from 5 Mbps to 1.6 Mbps. We can also see four drops of throughput which indicate 4 handovers. The node based distance estimation algorithm shows a smaller drop in throughput with a minimum at 2.2 Mbps, while the region based distance estimation algorithm shows the best performance with a throughput that doesn't go below 3.6 Mbps. From this we can say that by using the region based distance estimation handover algorithm we can reduce the throughput penalty during a handover by 50% in regards to the naive algorithm, which leads to a more seamless handover process. Figure 6 show the average throughput during the handover process. We see that during the handover period the average throughput of the naive algorithm is 4.47 Mbps, 4.67 Mbps for the node based one and 4.87 Mbps for the region based one. We can clearly see that we have a higher average throughput during the handover process with the distance based algorithms, the highest being with the region based algorithm which has a 10% better throughput then the naive algorithm.

VI. Conclusions

In this paper we presented handover algorithms that are AP driven rather then client driven. We achieve this by using network virtualization and high level abstractions which are provided by the 5G-EmPOWER framework. These abstractions enable us to create proactive and transparent handovers that are steered by a centralized controller. At the controller side we use RSSI values to estimate the distance of the user with regards to the APs. This information can be used to estimate the user's distance and create a better handover decision. By exploiting the distance information we were able to reduce the amount of handover and avoid unnecessary one. Also, we were able to reduce the throughput penalty during a handover by 50% which leads to a more seamless handover process.

The results in this paper show that there is definitely room for improvement of the handover process in Wi-Fi. As shown here, a handover can be AP driven and can utilize information such as the distance information to make smarter handover decisions. Using 5G-EmPOWER it is possible to create a seamless and client transparent handover and by utilizing the distance between the user and the WTPs unnecessary handovers can be avoided.

In future work, we plan to elaborate on the handover algorithms by investigating more complex multi-user scenarios and taking the historical movement of the clients into account.

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