# A Utility Based Access Point Selection Method for IEEE 802.11 Wireless Networks with Enhanced Quality of Experience

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***Abstract*— Over the past ten years, many solutions have been proposed to address the problem of access point selection in IEEE 802.11 Wi-Fi networks. The standard, which recommends that user devices select an access point based on received signal strength (RSS) has many shortcomings and leads to poor performance. Many of the solutions proposed lead to better performance under some circumstances and with a particular goal in mind. However, in general, each solution has shortcomings as well. In this paper, techniques in access point selection are surveyed dating back to 2002. These approaches are compared and classified, and the problems and limitations are identified. Lastly, a utility-based method which is proposed which is generalized and may take into account a wide range of interests and goals. The performance of the proposed utility-based approach is evaluated with some preliminary simulations in ns3.**

***Index Terms*—Wireless Networks; Utility; Network Selection; Game Theory; Access Point; IEEE 802.11**

## I. INTRODUCTION

ACCESS POINT selection has been a well-studied problem in wireless networks since at least 2002 when it was noted that problems existed with typical IEEE 802.11 based wireless networks, which used only the received signal strength (RSS) to determine which access point (AP) a client node should use to attach itself to the network [1]. At the time, wireless local area networks (WLANs) were much less common than today, and typically one network had only one AP. While RSS is a simple and quick method to select an AP, it can lead to imbalanced loads between APs, inefficient rate selection and selection of APs with poor throughput, delay and other performance metrics. There are several contributions of this paper. First, a detailed survey of the related approaches for AP selection in IEEE 802.11 networks over the past ten years is given. Secondly, a comparison and classification of these techniques is provided. Third, a unique utility-based AP selection approach is introduced. This approach is meant to be a naïve first attempt at developing a more general game theoretic framework that may be applied to select both APs and attachment networks in heterogeneous wireless networks. The proposed utility-based technique is evaluated against the standard IEEE 802.11 RSS-based AP selection algorithm. Many previous single objective techniques have been proposed and portions of these approaches may be combined to create a multi-objective approach which is the aim of this work. While "even discovering alternatives is expensive" [2], this paper proposes a multi-objective approach because next generation wireless networks require a good choice to be made. Consider networks where, in addition to AP selection, the user device must also determine which radio access technologies (RATs) to choose from. This work is a preliminary step in this direction by first applying a multi-objective selection to a single technology (Wi-Fi). The remainder of this paper is organized as follows. In Section II, a classification and comparison of the previous approaches is given. The proposed approach and methodology is discussed in Section III. In Section IV, the performance of the proposed approach is evaluated. Lastly, in Section V conclusions and future work are given.

## II. COMPARISON AND CLASSIFICATION OF EXISTING AP SELECTION ALGORITHMS

There are several established ways to classify the existing work in this area. AP selection can be classified as active or passive, centralized or distributed, or according to goal. Active AP selection usually initiates an active association attempt to all of the potential APs and makes some brief measurements to gauge how good a potential AP might perform with respect to some performance metric. For instance, in [3], the user device associates and briefly pings several well- known servers on the Internet to determine which AP has the best Internet connection. While this gives a very accurate idea of the network conditions, the time taken to determine this is very high compared to passive approaches. Passive AP selection usually observes the environment, beacon frames, and probe frames to make an estimate of which AP may be the best. Passive selection is almost always quicker because during active selection, certain network functions such as obtaining a DHCP lease may take 10-20s [2]. Passive selection generally requires no modification to IEEE 802.11 protocols, while active approaches may require modification in the case where extra information is exchanged between the AP and the user device. There is also a sort of hybrid AP selection. In the literature this category is also known as AP assisted [4, 5, 6, 7] In this case, the user device may provide some limited information to the AP which may make use of this information and provide feedback to the user device to help decide on an appropriate AP. For instance in [8], the user device provides information on which AP beacons it received to the AP with which it wishes to associate. The APs may then use this information to determine which other APs may be interfering with it and help the user device determine how likely interference is to occur if association occurs with the particular AP.

Another way in which AP selection schemes may be classified is centralized or distributed. The case where the user device makes the selection based on local information and measurements is considered distributed because each device makes its own decision. This is overwhelmingly the most common type of approach [3, 4, 9, 10, 2, 11, 8, 12, 13]. When the AP plays a more active role, and there is co-ordination between the APs to try to balance load, this is considered centralized. While centralized approaches may provide a more re realistic picture of the network and are good at equally balancing load, there is high overhead and low scalability in terms of APs compared with distributed approaches. However, despite these drawbacks, in small scale networks, the performance of centralized approaches can often outperform RSS-based and decentralized approaches [14]. A radically different somewhat centralized approach is proposed in [6] where users are able to file reports on public Wi-Fi APs. Users then download and cache these reports and use them to help select APs that fit their criteria.

Lastly, approaches may be classified based on the goals of the approach. The majority of the AP selection techniques surveyed have only one objective – to maximize throughput. There are very few which consider other important objectives such as delay, jitter and other QoE metrics. However, many of the more modern approaches seem to be moving in the direction of using multiple metrics since a single metric in isolation does not seem to work in all circumstances [5]. Our proposed approach takes this into account, which makes it a more useful approach for modern users who make use of a wide range of applications that have varying requirements other than just high throughput. One important technique that may be used in our approach is the standardized Roaming Information Code (RIC) proposed in [7]. This specification defines the manner in which data may be exchanged in probes and beacons between APs and user devices. This may be a good method to exchange the metric information required in order to define the utility of an AP at the user device.

Some of the most modern approaches take into account multiple metrics, for example, [15] proposes a game theoretic model which takes into account the users' preference for cost vs. throughput and tries to match the user with the best AP given this preference. However, this approach does not consider other important performance factors such as delay and jitter. [10] Also uses multiple metrics, but again only uses them to make an estimate of the best throughput out of the available APs. One of the most recent techniques which uses multiple metrics is [16] which proposes a cross-layer AP selection designed for distributed queuing. It is an interesting approach which allows for co-operation of neighboring APs. Multiple metric systems are becoming more common in other types of QoE based approaches, for instance, [17] which uses multiple metrics for a cognitive radio MIMO system.

In Table 1, each of the approaches surveyed are compared according to the classifications outlined previously. The table allows for quick comparison of each of the techniques. In the third column of the table, **A**/**P**/**H** stands for active, passive and hybrid respectively. In the fourth column, **C**/**D** stands for centralized and distributed respectively.

TABLE I - COMPARISON AND SUMMARY OF AP SELECTION TECHNIQUES

| Ref. | Approach | A/P/H | C/D | Goals |
|---|---|---|---|---|
| [3] | TP estimation based on frame timing | P | D | Maximize TP, minimize RTT |
| [4] | Estimate MAC layer bandwidth based on beacon delays | P | D | Choose the AP with the highest estimated bandwidth |
| [5] | Estimate throughput based on AP capacity in presence of interference, duty cycle and quality of link | H | D | Select the best AP using multiple metrics which estimate TP |
| [6] | Reporting software allows subjective rating of APs. Relies on trust and offline caching | H | C | Choose the AP with the highest ranking according to set criteria based off other users' reports |
| [7] | Standardized Roaming Information Code (RIC) to provide information exchange between AP and STA | H | D/C | Provides mechanism for information exchange, but no defined method for choosing an AP |
| [8] | TP estimation based on frame timing [3] + inter and intra BSS interference | H | D | Maximize TP while minimizing impact on others |
| [9] | TP to Internet servers | A | D | Find which AP has the best Internet connection |
| [10] | Use a neural network to estimate the TP of an AP based on four measured metrics | P | D | Select the AP with the highest estimated TP based on metrics |
| [11] | Determine whether it is worthwhile for a mobile user to physically move closer to another AP | P | D | Based on distance to AP and "load" determine whether to move |
| [12] | RSSI and radio interference estimated from frame retransmissions (using two Wi-Fi interfaces) | P | D | Choose the AP with the highest RSSI and lowest interference |
| [13] | Uses a new "metric" called estimated available bandwidth (EVA), based on # of busy and idle timeslots observed during scan period | P | D | Choose the AP with the highest EVA |
| [14] | TP based on data rate and error rate | A | C | Choose that AP with highest TP |
| [15] | Game theoretic, non-cooperative, utility based on cost & TP | P | D | Find the best match based on user preference |

## III. Proposed Approach and Methodology

Since the majority of existing approaches adopt the passive approach, and because it requires no modification to the AP the proposed approach also makes use of this technique. This means our approach will only make use of measures and metrics without actually interacting with the AP beyond the usual probe mechanisms that already exist. Our approach will also be distributed, since the centralized method also requires modification to the AP. There are four strategies for AP selection which will be evaluated in this paper. First, the best AP is selected according to the closest distance. The second is where the devices will select the AP with the highest data rate. The reasoning is that APs with higher data rates will have greater capacity to handle more users. This approach is inspired by [14]. The third strategy is one where the devices select the AP with the lowest delay from when the probe is sent to when it is received. This approach is similar to that of [4]. The fourth strategy is a utility-based strategy. In this case, all three of the previous metrics are collected. The metrics are normalized between one and zero. Then, each metric is given an equal weight within the utility function. The utility value falls between zero and one and is used to rank the APs across all metrics. The AP with the highest utility value is selected.

## IV. Performance Evaluation

To evaluate the performance of AP selection, the ns3 simulation tool was used. In ns3, there does not seem to be support for channel scanning. A Wi-Fi AP and station are inherently linked together by the physical channel defined in the simulation script, and there does not seem to be a way that a single Wi-Fi interface on a station node is able to select and switch between physical channels. Because of this, a rudimentary AP selection algorithm was implemented for ns3 and compared against the various methods for selecting an AP below. The simulation covers a small area with two APs so that all of the station nodes are able to communicate with either AP regardless of their location. For each run of the experiment, the station nodes are distributed randomly around the simulation area. Each scenario is repeated 30 times and the box-and-whisker plots show the first and third quartiles along with the median. The upper and lower lines represent the minimum and maximum values. These plots allow easy comparison of medians and some sense of variation between results. The two APs are located directly in the middle in the y-direction and at the 1/3 and 2/3 points in the x-direction. One AP is set to the IEEE 802.11b standard which has a maximum rate of 11Mbps in ns3 while the other AP is set to use the IEEE 802.11g standard which has a maximum rate of 54Mbps in ns3.

### A. Single Slow AP Experiment

First, in order to establish single AP performance, an experiment is performed using the above topology with a single AP with a fixed data rate of 1Mbps. This is to establish the improvement which may be gained from AP selection. All of the client nodes are located within a 30x30m area around the AP so that all are within communication range of the AP. The clients use a CBR stream of 0.5 Mbps each from the GW attached to the APs in the topology.

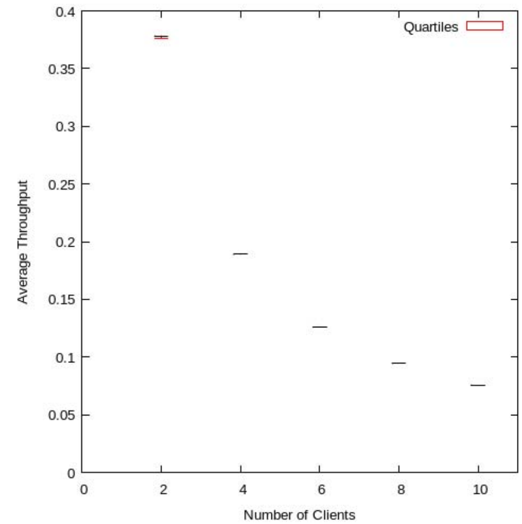


Figure 1 - Average Throughput per client (Mbps) - Single slow AP, multiple clients.

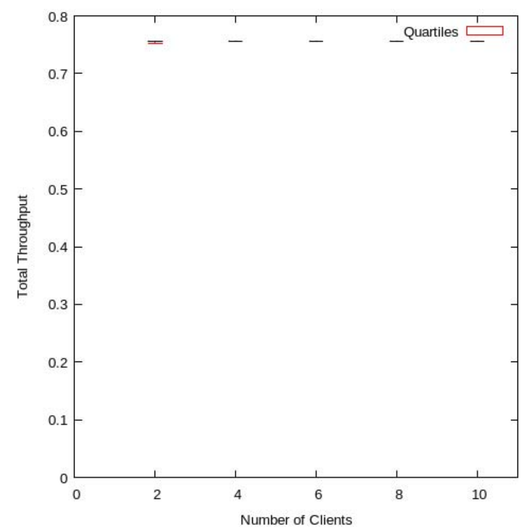


Figure 2 - Total Network Throughput (Mbps) - Single slow AP, multiple clients.

Figure 1 shows the degradation of average throughput as more clients are connected to a single AP. The results are as expected since the link is limited to 1Mbps. With two clients, each gets slightly less than 0.5 Mbps and with ten, each gets slightly less than 0.1Mbps. The rest is likely taken by protocol overhead. In Figure 3, the total throughput of the network is limited to roughly 0.8 Mbps which shows that the AP is already becoming congested. With each user receiving at best about 0.4 Mbps (2 users) and at best about 0.1 Mbps the range of applications available to the users becomes limited.

### B. Single Channel Two AP Experiment (One Slow, One Fast)

Next, the experiment is expanded to include two access points, one slow (IEEE 802.11b with a fixed data rate of 1Mbps) and one fast (IEEE 802.11g with adaptive data rate of up to 54Mbps). Both APs are located on the same channel, and the user device selects the AP according to the ns3 selection mechanism, which seems to be whichever probe packet arrives first.

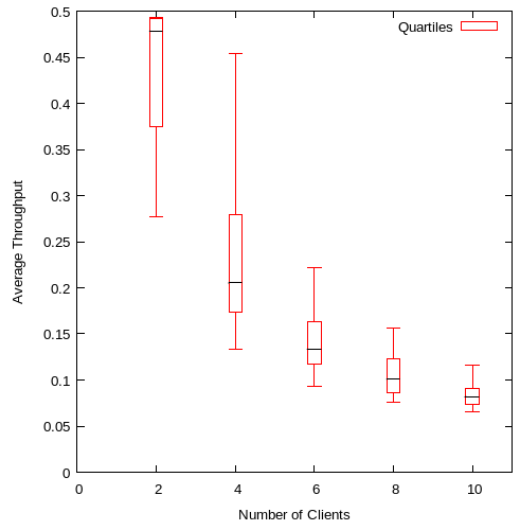


Figure 3 - Average Throughput per client (Mbps) - Two APs, multiple clients, single channel.

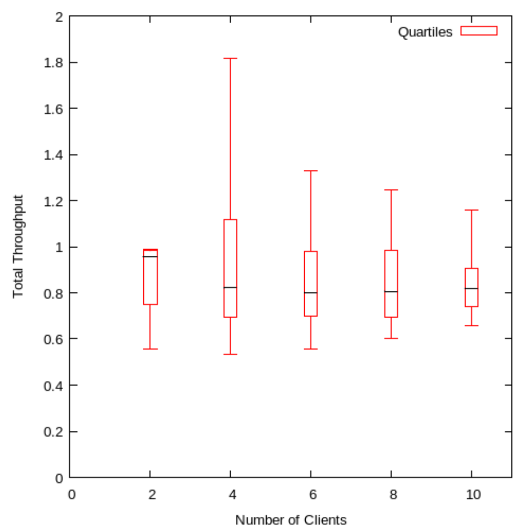


Figure 4 - Total Network Throughput (Mbps) - Two APs, multiple clients, single channel.

Figures 3 and 4 show the average and total throughput for this scenario respectively. Compared with Figure 2, the average throughput per client in Figure 4, where there are two APs, similar average performance is observed, however, there is much more variation in the results. For instance, with four clients it can be noted that the performance is sometimes as good as the single AP case with only two clients. However, because of the poor selection mechanisms and likely interference between the APs being on the same channel, there is not much improvement in performance. In Figure 4, compared with Figure 2, it can be noted that the total network throughput is almost always better with two APs compared with one, however there is not a drastic performance improvement as one might expect by adding another AP which has a maximum rate of up to 54Mbps. This is likely because the rate adaption algorithm is slowing the AP down to 1Mbps due to interference and the presence of the other slower AP nearby.

### *C. Double Channel, Two AP Experiment (One Slow, One Fast) – Simultaneous Transmission*

In order to overcome the interference problem with operating both APs on the same channel, new experiment is performed with both APs on separate channels. Unfortunately due to the way in which ns3 works, it did not seem possible to do this with a single Wi-Fi interface, so essentially each client in this experiment has two interfaces and can transmit on each simultaneously. Results also show the upper bounds on performance in the case where the user device actually has two interfaces which can split the traffic across each. The following experiment modifies this further and only allows one to transmit at a given time which is the most realistic scenario, and the most interesting for this work.

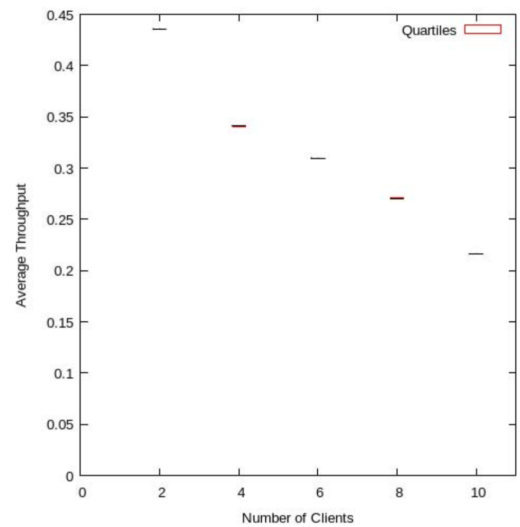


Figure 5 - Average Throughput (Mbps) - Two APs, multiple clients, two channels.

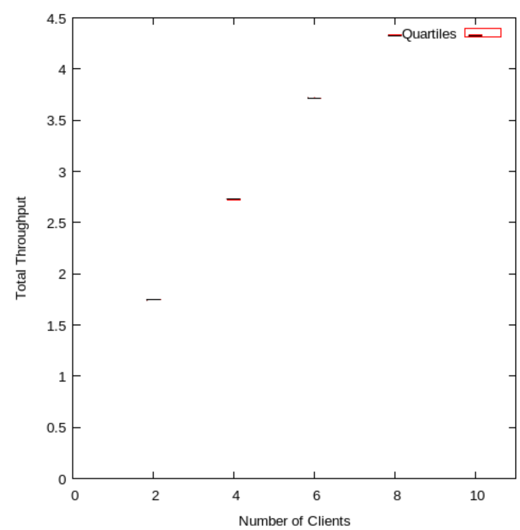


Figure 6 - Total Network Throughput (Mbps) - Two APs, multiple clients, two channels.

In Figure 5, the average throughput is more similar to that of the single AP case, with much less variation. However, compared with Figure 1, the performance degrades much less quickly as the number of clients increase. Figure 6 shows the total throughput of the network as the number of clients increase. Since each user device can actually transmit on both channels simultaneously, it is possible to obtain a maximum throughput of 1.0Mbps per client. In this case, we see similar variation as we do in Figure 2, but rising total throughput because one of the APs has a higher data rate, rather than the flat total throughput we see in Figure 2. The following experiment shows a more realistic case where only one channel may be active at once.

### *D. AP Selection Experiment - 2 AP (One slow, one fast) – Single Interface Transmission*

Since the previous experiment allows simultaneous transmission on both channels, there is no AP selection being performed. In order to evaluate AP selection choices, one final experiment is performed. In this experiment, there are still two APs and two channels, but a user device is only allowed to transmit on one interface or the other, but not both at once.

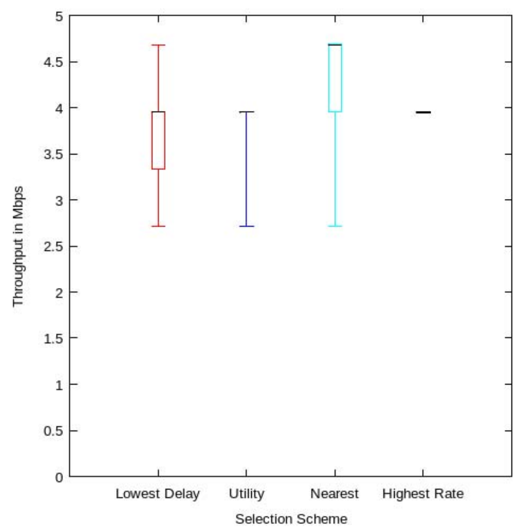


Figure 7 - Total Network Throughput (Mbps) - Two APs, two clients, two channels, single transmission

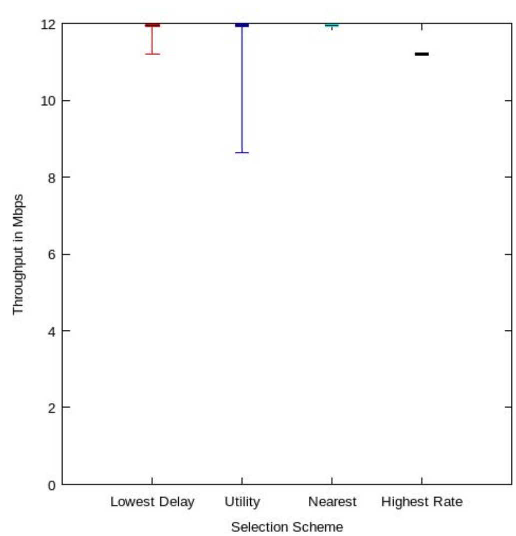


Figure 8 - Total Network Throughput (Mbps) - Two APs, ten clients, two channels, single transmission.

Also, to try to put strain on the network at smaller sizes, the CBR rate is increased at each client to 2.0Mbps. The following are the results of this experiment. In Figure 7, the best a client device should be able to do is 2.0 Mbps, however there is some extra traffic which is able to get through during the brief time it takes to bring down one interface and start the next during the switch so in some cases there is slightly higher than 4.0Mbps being sent per client. This means we can interpret all of the approaches to be more or less equal, with perhaps the exception being highest rate, which has very little variation, making it the best strategy in this case. Because of this, since the utility approach makes use equally of the nearest and lowest strategies as well, it also suffers from making these less than optimal choices in some cases.

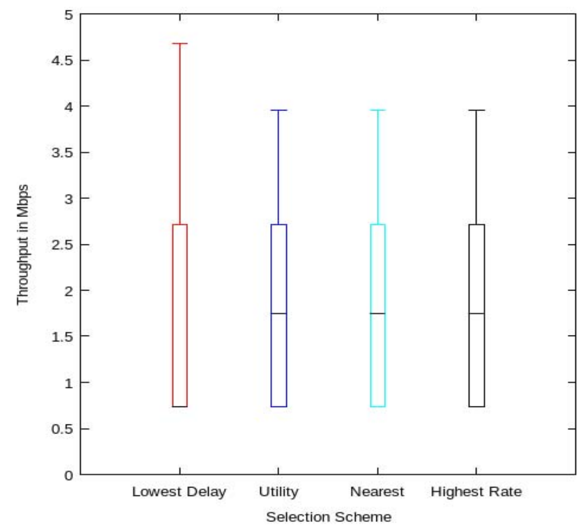


Figure 9 - Total Network Throughput (Mbps) - Two APs, two clients, two channels, single transmission, far distance.

In Figure 8, all of the medians are very close, however, the highest rate is no longer always the best strategy. As the network becomes more loaded, it is sometimes better to choose the nearest or lowest delay alternative. The best strategy, in this case, seems to be choosing the nearest, since it results in the highest median and least variation. While the median for utility is also as high as the lowest delay and nearest approaches, there is much more variation in this approach, with the lowest throughput being slightly more than 8.0 Mbps total compared with the others which record a lowest throughput of 11.0 Mbps. In order to gain further understanding, this is repeated experiment again with a farther distance to see if there are any differences with farther distances between the APs. The area size is changed from 30x30m to 120x120m. In Figure 9, similar results may be seen for all approaches, however with only two clients, the network is not particularly strained yet. One thing to note is that there is now much more variation in the results. There is no longer a clear best strategy either, since all approaches have so much variation. In Figure 10, it is noticeable that choosing the AP with the highest rate is clearly not the best strategy, even though in Figure 7, it was. One thing that can be seen, so far, from the results is that, while the utility-based approach may not be the clear best in any particular scenario, it is good at being a stable choice. It is also rarely the worst choice. Since it takes a balance of all of the other metrics, which at times can produce very good or very poor choices, it is a strategy which selects more predictable outcomes.

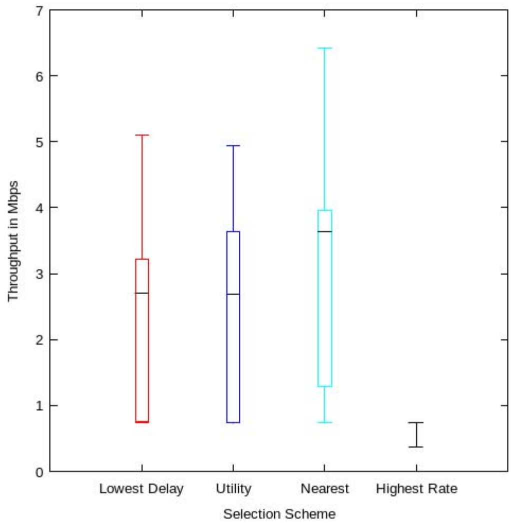


Figure 10 - Total Network Throughput (Mbps) - Two APs, ten clients, two channels, single transmission, far distance.

## V. Conclusions and Future Work

In this paper, a brief survey and classification of recent works in AP selection for IEEE 802.11 Wi-Fi networks was provided. Furthermore, an overview of the evaluation criteria for each approach was provided to allow the reader to gauge the accuracy of the claims provided by the researchers. It was noted that the majority of the approaches make use of few metrics and almost always estimate the throughput or bandwidth of APs to make the selection. Very few make use of other common important metrics for QoE such as jitter and delay. A utility-based approach which aims to solve this problem was proposed. While the early results are promising, the utility-based approach combined with a more formal game theoretic framework is expected to yield further improvements for QoE. This work can further be extended beyond IEEE 802.11 Wi-Fi networks and into heterogeneous networks. The same principles can be used to determine to which access technology a user device with multiple technologies available should attach. As a result of this work a Wi-Fi channel scanning module for ns3 which will allow the type of experiments presented in this paper to become more commonplace has been developed and will be released.

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