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A MODEL PROPOSAL TO OPTIMIZE BANDWIDTH USAGE IN MULTI-ACCESS WIRELESS NETWORKS

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Original scientific paper
Distribution of load among multiple access points, and therefore, optimizing the total throughput is one of the problems of wireless local area networks when there is more than one access point available in the network. It is not easy to balance the load when wireless hosts associate with one access point by using only the Received Signal Strength Indicator (RSSI). In this study, a new model which increases total throughput in a wireless local area network is proposed. The proposed model is mainly based on the prediction of the loads of all the available access points checking both their wireless and Ethernet interfaces and the association to the least loaded one. It is a host-based model and does not require any changes on the network infrastructure. The tests performed on the real wireless local area networks prove the applicability of the proposed model.

***Keywords**: Wireless Communication, Wireless Local Area Network (WLAN), IEEE 802.11, load balancing, throughput maximization*

Prijedlog modela za optimiziranje uporabe širine pojasa u bežičnim mrežama višestrukog pristupa

Izvorni znanstveni članak
Distribucija opterećenja između nekoliko pristupnih točaka te, stoga, optimiranje ukupne propusne moći predstavlja jedan od problema bežičnih mreža lokalnog područja kad je više od jedne pristupne točke dostupno u mreži. Nije lako uravnotežiti opterećenje kad se bežična čvorišta povezuju s pristupnom točkom samo uporabomm indikatora jačine primljenog signala (RSSI - Received Signal Strength Indicator). U ovom se radu predlaže novi model koji povećava ukupnu propusnu moć bežične mreže lokalnog područja. Predloženi se model uglavnom zasniva na predviđanju opterećenja svih dostupnih pristupnih točaka provjeravajući i njihova bežična i Ethernet sučelja i povezivanje s najmanje opterećenom. To je model utemeljen na čvorištu i ne zahtijeva nikakve promjene na infrastrukturi mreže. Ispitivanja provedena na postojećim bežičnim mrežama lokalnog područja dokazuju primjenjivost predloženog modela.

***Ključne riječi:** bežična komunikacija, bežična mreža lokalnog područja, IEEE 802.11, balansiranje opterećenja, maksimalizacija propusne moći*

1 Introduction

Recent advances in computer networks have changed the way of getting and storing information. All kinds of information can be accessed instantly if you are connected to the Internet. People access the Internet for different purposes such as entertainment, business and social interactions. Consequently, people want the Internet to be accessible even while they are moving, and that leads to an increase in popularity of wireless networking. However, wireless networking has several problems to be solved to give better services to users [1 ÷ 5]. Load balancing can be regarded as one of the popular problems of Wireless Local Area Network (WLAN). Handoff from one access point (AP) to another due to mobility may result in some APs to be overloaded. Received signal strength indicator (RSSI), that IEEE 802.11 is based on, does not give any information about the load of an AP. The AP with the highest RSSI may be over-loaded while another AP with relatively lower RSSI is idle. This situation causes ineffective usage of total available capacity. Therefore, it is required to develop a solution to balance load among APs serving in the same coverage area and increase the total throughput. However, the distribution of wireless hosts among APs concerning their load is a difficult task because of the movement ability of those hosts [5]. Researchers have proposed some solutions to this problem. The proposed solutions may be grouped into four categories: AP-based approaches, central server-based approaches, host-based approaches and combined approaches.

AP-based solutions are generally proprietary solutions of AP producers [6]. In addition to producers, some researchers claim that if handoff is done by APs instead of hosts, then the load balancing could be achieved. Manodham et al. [7] support this idea by defining a novel AP with two transceivers in which the additional one is used for communicating with neighbouring APs for analysing load and deciding handoff time. Velayos et al. [8] suggest that an agent running on AP should monitor network status. The agent sends and receives information regarding load of APs and selects the best candidate host for transfer.

Some researchers argue that load balancing can be achieved by using a central server. Bejerano et al. [9] suggest that, by using an algorithm and collected information, a network operation centre can design a load balanced situation and inform connected hosts about new ideal associations. Then, the informed hosts may shift to idle or lightly loaded APs. Jabri et al. [10] propose a central load balancing server which downloads parameters from APs and tries to find the best host distribution among APs by using a special algorithm.

The host based approach has been favoured by Chen et al. [11]. They suggest that probe delay data can be an indicator of load on an AP. Especially, if more than one probe is analysed to calculate a mean probe delay, it can be a more accurate indicator. Transmission delay can be longer due to exponential backoff time usage of IEEE 802.11, in case the network traffic is heavier. Probe responses are examined and the APs over SNR threshold are selected as candidates. After scanning all the available APs, the one with minimum mean probe delay is chosen as the least loaded AP to associate with.

Some solutions to load balancing need to be run on both AP and wireless hosts (combined approach). Sheu and Wu propose an algorithm, i.e. Dynamic Load

Balancing Algorithm (DLBA), running on both APs and wireless hosts [12]. Another solution in this category is proposed by Papanikos and Logothetis [5]. They suggest that the wireless host should be associated with an AP according to the number of connected workstations and the mean RSSI value. Since standard protocols do not have information about either numbers of workstations connected or means of RSSI, protocol modifications of beacon and additional features in probe responses are required to implement their proposal.

Although these efforts have defined the problems and suggested some solutions, none of them has been accepted as a standard by IEEE 802.11 working group. IEEE 802.11 working group has experienced some improvement in QoS based on load balancing studies, but it has not been finalized yet [13]. In this paper, a novel load balancing and throughput maximization model is presented. The load should be distributed among available APs according to their bridging capacity taking into account both wireless and Ethernet interfaces. Whenever the proposed model runs, some parts of the load in the over-loaded AP is transferred to relatively less loaded APs, and finally, the load of APs converges to a degree proportional to the capacity of each AP. In this definition, the load transfer is done by disassociation of hosts having low bandwidth usage from the over-loaded APs and their association to the less loaded ones. The proposed solution uses a host-based approach, and it is a dynamic solution since the load of APs is checked periodically during a specific session.

Since all analyses and decision making procedures are carried out at host level by an agent running on each host, the proposed solution has advantages of being fully decentralized and autonomous. There is no need for a centralized server or AP modification. It can be used in any WLAN environment. The proposed model also considers load balancing from a different point of view compared to previous studies. The difference is that it takes both interfaces into account during load balancing and throughput maximizing efforts. Therefore, the model is different from previously proposed host-based studies.

2 Proposed model

An access point (AP) in a WLAN connects wireless hosts to the fixed (wired) network. When multiple access points are available in the same WLAN, hosts are associated to one of the APs providing the highest signal strength at connection time. If a wireless host is mobile, it can switch to another AP providing more powerful signal when signal strength of the connected AP goes below a certain threshold level. However, hosts do not consider the traffic load of APs during the initial or subsequent associations. This may cause unbalanced traffic load on APs, and therefore it may result in inefficient usage of the total wireless capacity.

The traffic flowing in a WLAN uses both the radio and Ethernet interfaces of an AP. To predict the load of the AP, checking only the radio interface does not give enough information. Therefore, an approach which evaluates both the radio and Ethernet interfaces of the AP will definitely give more accurate information about the load of the AP. For example, consider the network configuration given in Fig. 1. The radio interface speeds of the two APs are 54 Mb/s. Although there are many hosts on the network segment of the AP-1, the connection bandwidth of this segment is lower (10 Mb/s) than the other network segment where there are less hosts and the connection bandwidth is 100 Mb/s. In such a configuration, the wireless hosts connected to AP-2 will likely get better service compared to the hosts connected to AP-1. However, predicting the bridging capacity of AP-1 just considering 54 Mb/s wireless link gives wrong information.

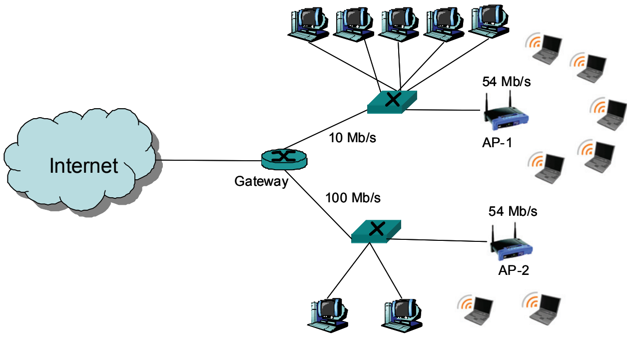

Figure 1 A typical wireless network showing connection of APs to the backbone with different bandwidths

The proposed model is based on dynamic monitoring of bandwidth usage status of all APs under consideration and association with the one offering the best access rate considering also the Ethernet interface. Each host dynamically measures its bandwidth usage and decides whether it is a low bandwidth usage host (LBU host) or not. If it is an LBU host, then it associates to other available APs one-by-one in order to check their loads. If a better AP, which offers higher access rate compared to the current one, is found at end of this scanning phase, the wireless host makes handoff to this AP as the last action.

```
ALGORITHM
BEGIN
   IF not connected THEN connect the AP giving the
                                          highest RSSI
   Scan all the channels and make a list of all available
                                                   APs
   IF there is more than one AP in the list THEN
      Get minute based usage rates for last three minutes
      Calculate average rate
      IF average rate is less than the LBU threshold
      THEN
         Select host as an LBU host
      IF host is an LBU host THEN
         Freeze TCP
         FOR each AP in the list
            Associate the AP
            Send pre-loaded ICMP packages to GW
            Calculate an access rate value using the
                                             responses
         Determine the AP giving best rate and associate
         Restart TCP
   Wait for a random duration
END
```

Figure 2 Algorithm of the model

In the proposed model, the load of APs is predicted using the radio and Ethernet interfaces. For this reason, the network traffic passing through both interfaces should be examined. To achieve this, the model requires another node in the network. A far end node should be determined in such a way that the route to it should pass over both interfaces. For simplicity, this node can be the gateway of the local area network. Considering Fig. 1, AP-1 and AP-2 are connected to the same gateway. In this scenario, the access rate between the host and the gateway is measured through AP-1 and AP-2 separately by sending probe packets, and the one giving the best rate is determined considering probe delays.

Fig. 2 summarizes the algorithm of the model running on each host. First of all, the wireless host should connect to an available AP in the environment using RSSI. Then, the host checks whether there are other available APs in the environment. If there is not any alternative AP, the algorithm passes to a waiting mode for a random duration. On the other hand, if there is at least one more alternative AP to connect, the wireless host determines whether it is an LBU host or not. In case it is an LBU host, the algorithm continues with the next step, otherwise it skips to the waiting mode. The next step is the scanning phase of all the available APs to determine the best one. In this step, the best AP is determined by associating to alternative APs one-by-one and sending probe packets to them. Pre-loaded Internet Control Message Protocol (ICMP) packets are used as probe packets. At the end of the scanning step, the algorithm calculates the best AP and passes to it (if it is different from currently connected one). Finally, the algorithm waits for a random time and restarts.

According to the model, if a host is determined as an LBU host, then it makes a series of temporary handoffs to find the best AP. Therefore, the determination of LBU hosts for such an action is an important decision. If a high bandwidth usage host is selected for this purpose, its association with a less loaded AP may change its status to an overloaded one, and the switching process may continue with subsequent meaningless series of handoffs. The reason to select an LBU host for switching is that its load affects the newly connected AP to a limited extent. In addition, already associated hosts of the new AP are not seriously affected by the new coming host since it is just spending a limited amount of served bandwidth. After switching of a host, the overloaded AP, which was the one associated before, starts to offer better performance to its clients after this handoff. Finally, overall throughput of the network is improved to a certain extent at the end of some series of handoff processes done by LBU hosts in the wireless network.

As seen in the last line of the algorithm, the model waits for a random timeout period. The aim of using a random timeout period for the next run of the algorithm is to prevent all the LBU hosts handover to other APs at the same time. It is because if all the LBU hosts run the model simultaneously and temporarily handover to the next AP together, they all may be associated with a certain AP resulting in false decision about its load status.

The model also considers the mobility of the wireless hosts. If a host moves, its RSSI may start to decrease and may result in the association with another AP serving better RSSI. The proposed model does not prevent such handoffs. However, such handoffs caused by the nature of wireless communication may affect the aimed performance of the proposed model. For this reason, the model runs without waiting for the timeout period after such handoffs.

An important issue regarding handoff execution is keeping TCP's congestion window size at its current state. Since the model requires subsequent handoffs, the host may be affected by the restart of the slow start phase of TCP's congestion window management system by losing packets whenever handoff occurs. Even low traffic usage hosts may face with this problem and this problem decreases the total throughput. For this reason, necessary measures should be taken in order to keep the congestion window at its current status. As proposed by Goff et al. [14], sending zero window size propagation just before handoff freezes the re-transmit timer of the sender and enters it into a persist mode. After a successful handoff, a non-zero window propagation sent by the receiver restarts transmission of the sender at previous window size, resulting in no decrease in the congestion window. In the algorithm, "freeze TCP" and "restart TCP" lines are defined for these actions. The problem with predicting correct handoff time which has been criticized by Lee et al. [15] and Qu and Zhang [16] is not an issue in the proposed model, since handoff is requested by the host itself but not a mandatory action activated by a decrease in RSSI. The host having the intention for handoff can activate precautions before the handoff process and can keep TCP transmission at its original state.

3 Results and discussion

The proposed model is tested on a real world testing environment. In this way, it is intended to see not only the contribution of the model to load balancing and throughput maximizing effort, but also its feasibility. The test configuration is illustrated in Fig. 3. As seen in the figure, two APs (ASUS Wireless Router WL-520g) having the same coverage area are set up to bridge wireless hosts to wired infrastructure, with the SSIDs AP-Test1 and AP-Test2. A gateway with two Ethernet interfaces is used to access a server located out of the LAN. The functionality of the model, one AP is connected to the fixed network with a 10 Mb/s link capacity while the other AP is connected with a 100 Mb/s capacity. In order to minimize outer effects, only test APs are allowed to operate in the area covering test hosts. Channels of APs are manually set to 1 and 6 relatively to prevent possible signal interference. When active scanning is initiated manually at each host, it is observed that all APs have more than 30/100 link quality which is an aggregate value containing level of interference, bit or frame error rate, received signal strength, some of the timing synchronization value etc. depending totally on the driver of interface [17].

In the test environment, seven desktop computers equipped with external wireless adapters (ASUS WL-167g USB WLAN Adapter) are used. In order to ignore time required to ask IP addresses from DHCP server after handoff, all PC's are assigned static IP addresses. The

Ethernet interfaces are disabled in order to ensure all data communication at each host is carried out via the WLAN interface. In the test bed, each host has the ability to associate with both APs. Linux is preferred as the operating system of the wireless hosts and the server.

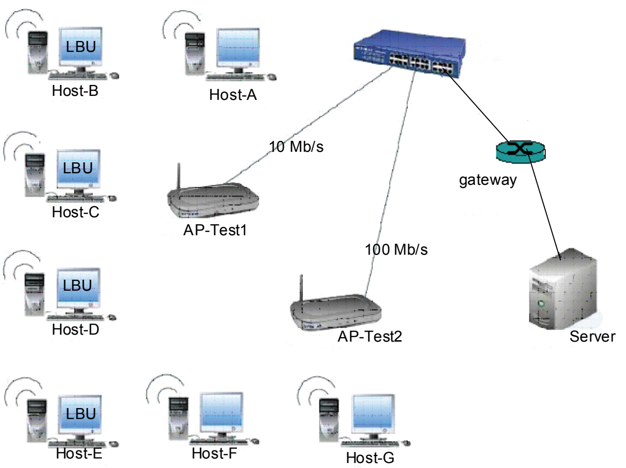

Figure 3 Test configuration

Using the algorithm mentioned in Section 2, necessary programs have been coded using Python programming language. During the tests, each host is charged to use some amount of network resources. 125 kBps (1000 kbps) is accepted as the threshold for LBU host candidacy. That is, only the hosts having throughput less than the specified threshold value run the algorithm. A value between 120 and 300 seconds is used as the random timeout period to restart the algorithm.

In the first test, wireless hosts are divided into two APs as three hosts are associated with the first AP and remaining four with other AP. Then, the hosts start to operate with charged load. The bandwidth usage of each host is recorded at their own log file on the basis of kB/min. In each log file, data on bandwidth usage has been indicated as the sum of data transmitted and received. During the first test, the proposed model has not yet been applied.

For the second test, the proposed model with coded programs is installed into each host and the necessary configuration is completed. The same associations of the hosts are manually arranged as in the first test. Then the model is activated to automatically check the load status of each AP, balance load, and increase the total throughput of WLAN. In this test, 1024 bytes ICMP packets (as probe packets) are used to determine the best AP to associate.

Table 1 Minute-based throughput (kB) of hosts and associated APs

Time (min)	Host A		Host B		Host C		Host D		Host E		Host F		Host G	
	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2
1		10828	5090			6407		6209		6963	8508			10620
2		10364		4842	6019			7010	5179		8067			10615
3		10651	4700		5952			7078	4921		7410			10006
4		10730	4679		5708		6977		4968		8335			10543
5		10216	4969		5278			6750	4953		8571			10720
6		10746		6287	5810			7272	5055		8085			10204
7		10591		6770	5698			7145	6149		8614			10413
8		10786		7000	5260		5638			5723	7027			10351
9		10412	6714			6121	5829			6971	8298			10160
10		10832	5850			7144	6130			6892	8558			10786
11		10741	5228			6522		5466		7078	7634			10750
12		10503	5406			5502		7304	5610		7815			10470
13		10758		6716		6679		7228	6092		8544			10820
14		10845		6824		6544		7223	6227		9142			10715
15		10482		6567	6347		6634			5447	9260			10084
16		10617		6209		6674	5865			7095	8086			10622
17		10000		6874		6111	5613			6847	8060			10295
18		9976		6959		6404		5999		7039	8128			10613
19		10444		6967	5932		6162			6463	7089			10194
20		10541		7000	5833		5744			6986	7610			10673
21		10434		7093	6178		4816			7147	8745			10341
22		10439		6811		6033		6502		6602	7142			10301
23		10562	6089		5647			7292		7178	7442			10545
24		10600	5286		5942			6910		7084	7103			10816
25		10349	5545		6977			6261		6909	8147			10292
26		10528	5568			6303		6925		6528	8802			10355
27		10291		6694		6463		6998		7225	9640			10305
28		10560		6739		6610		7055		7038	9132			10089
29		10737		6870	6438		6607		6331		7862			10482
30		10610		6912		5862	5309		5580		7274			10572
Total		**316173**	**65124**	**120134**	**89019**	**95379**	**71324**	**122627**	**61065**	**129215**	**244130**	**0**	**0**	**313752**
Total (WLAN)		**1627942**												

Table 2 Throughput and load distribution of APs for 30 minutes

	AP-test1		AP-test2		
	Throughput (kB)	Load Ratio (%)	Throughput (kB)	Load Ratio (%)	Total Throughput (kB)
First test (classical model)	774367	51,72	722823	48,28	1497190
Second test (proposed model)	530662	32,60	1097280	67,40	1627942

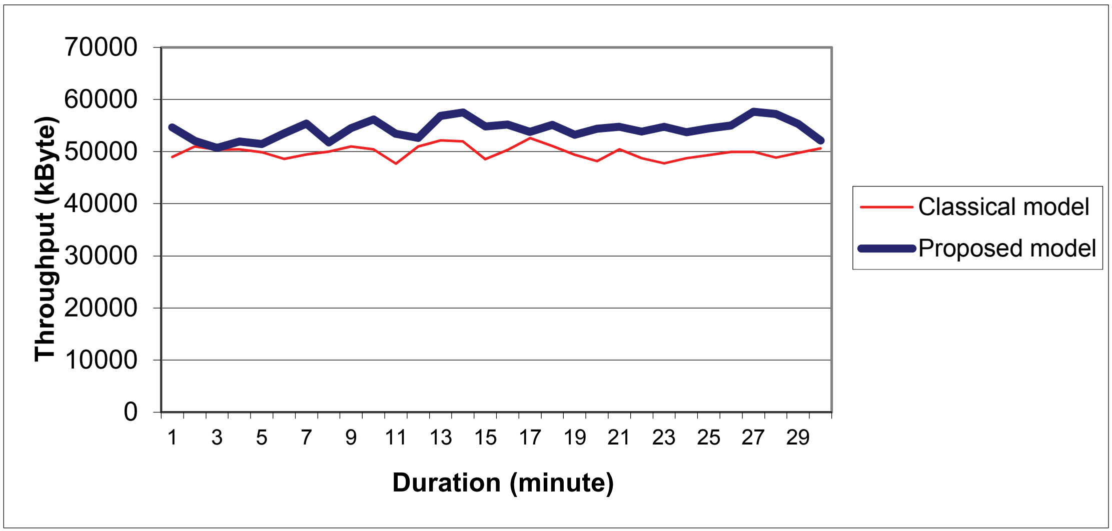

Figure 4 Comparison of minute-based throughput

During the test, the bandwidth usage of each host has been recorded as seen in Tab. 1. The non-LBU hosts (Host-A, Host-F, Host-G) have always remained connected to the same AP. However, the LBU hosts (Host-B, Host-C, Host-D, Host-E) have been observed to switch to the other AP depending on the calculated access rate of APs. As seen in the table, the LBU hosts have experienced with a subsequent series of handoffs to find the best AP during the test.

Table 2 compares the cumulative bandwidth usage values per AP taken from the first and second tests for 30 minute duration. Some amount of the load previously observed on AP-test1 has been transferred to other AP and finally, the total throughput has increased. When the transferred load ratio is calculated using the data given in the table, the following value is obtained.

Transferred Load =
= [(774367 – 530662)/774367] ×100 = 31,47 % .

That is, 31,47 % of the traffic of AP-test1 in the first test passes over AP-test2 in the second test when the proposed model is activated.

The graph which is given in Fig. 4 shows minute-based throughput values. As seen in the graph, starting from the first minute, the proposed model performs better than the classical wireless model. The graph in Figure 5 shows the cumulative throughput values initially and after implementation of the model. The total throughput achieved by the proposed model is higher than that of the classical approach. This result shows that the total and minute-based throughputs increase when the model is applied to the environment having at least two APs. The obtained benefit (contribution of the model) at the end of the test can be calculated as follows:

Contribution of the Model
= [(1627942 – 1497190)/1497190] ×100 = 8,73 %.

For the given scenario, the proposed model provides 8,73 % increase in total throughput of the WLAN. The amount of the gain changes depending on the scenario. For example, if all the wireless hosts shown in Fig. 3 are associated to AP-test1 at the beginning of test, then the gain of the model will be higher. On the other hand, if a balanced distribution of hosts is provided during a test period, then the proposed model will not provide any advantage. Notice that the aim of the proposed model is to provide load balancing considering link capacities and its advantage can be seen when there is at least one overloaded AP in the network and again when there is at least one AP with free capacity simultaneously. In such a case, some amount of the load on the overloaded AP is transferred to the AP with free capacity. The test result given above proves the successful operation of the model.

At each model run during the second test, if a host is an LBU host, it sends preloaded ICMP packets to the gateway in order to get access rate index value. This traffic has also been analysed in order to see the effect of the traffic created by the model. The cost of the model is calculated on an average of 0,00307 % extra traffic created by the model itself. When compared with the benefit obtained by the model, its cost is negligible.

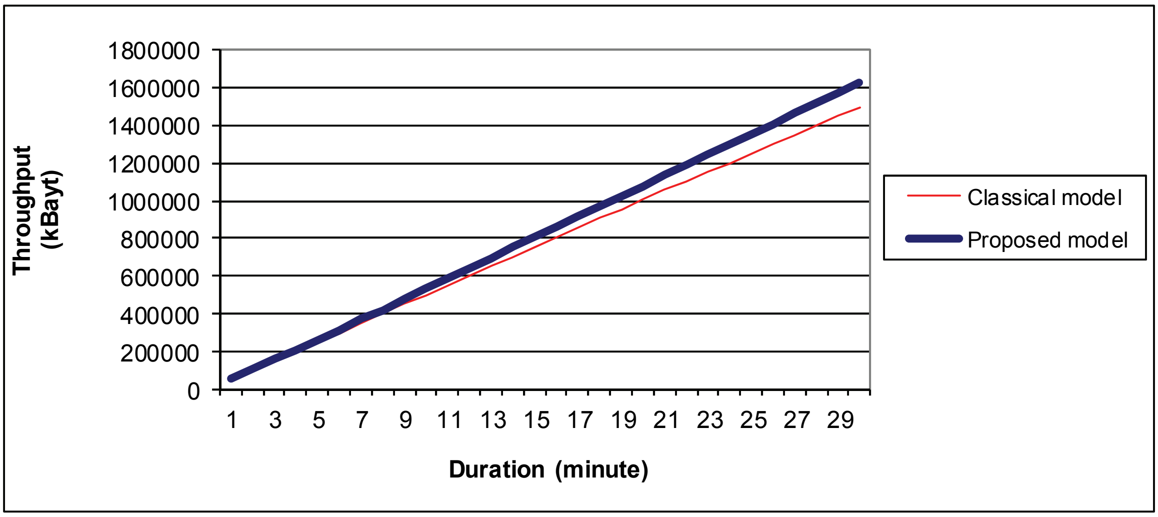

Figure 5 Comparison of total throughput

4 Conclusions

In this study, a novel model is proposed to increase total throughput in a WLAN having multiple APs. According to this model, a fully autonomous host dynamically monitors its bandwidth usage and decides its candidacy for temporary handoff. If it has a low band usage characteristic, it makes a series of temporary handoffs to all available APs in order to find the best one to associate with. In addition, the wireless host continues to check its bandwidth usage characteristic and access rate provided by available APs during the whole session. Therefore, the proposed model tries to balance the traffic continuously in a WLAN environment.

The test results prove that the use of the proposed model as an agent in a wireless host achieves better bandwidth usage in a multiple AP environment. If all the hosts in a WLAN run the agent, then all the APs will be loaded with respect to their capacity considering both interfaces. It is evident that a significant benefit can be reached by using such an autonomous and dynamic model regardless of brands of APs, security vulnerabilities arising from central server and protocol revisions (the proposed model does not require any changes in the wireless infrastructure). Another advantage of the model is that it is possible to implement and run it on a wireless host without changing anything related to IEEE 802.11. However, in an environment with a lesser number of wireless hosts or low traffic usage state where APs are not overloaded, the model may not be needed in order to balance load. It may also be true for the model to have no effect on balancing load where all available APs are overloaded. In such cases, the model runs as it is expected, but the model will have no contribution.

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