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Adaptive Traffic Offloading Method Based on OWN in Overlay Networks with LTE and WLAN

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Abstract: Traffic overload problem in the cellular networks has become crucial. In order to approach the problem of increasing traffic, an adaptive traffic offloading method based on a combination of Open Wireless Networks (OWN) and a biologically inspired attractor selection model is proposed in this study. This method provides a pragmatic way to keep load balance and reduce selfishness. Thus, it can improve the overall performance in overlay networks with 3GPP Long Term Evolution (LTE) and Wireless Local Area Networks (WLAN). Firstly, based on discrete Markov Modulated Poisson Process (dMMPP), a queuing model is considered to obtain the real-time network status in both LTE and WLAN. Secondly, by following the OWN architecture to develop the attractor selection model for offloading at the right time in order to accommodate unpredictable traffic demands in fluctuating environment. The whole wireless network can be managed in an autonomous, load balancing and robust manner by the global control which is under OWN and the autonomous decision of attractor selection. The simulation results demonstrate that the proposed mechanism can reach a tradeoff between the system delay and the handover times by realizing efficient traffic offloading.

Key words: Traffic offloading, 3GPP long term evolution, open wireless networks, attractor selection, discrete Markov modulated poisson process

INTRODUCTION

Due to the proliferation of mobile devices such as smartphones, tablets and laptops, the mobile traffic has increased exponentially. Furthermore, various traffic-hungry applications also promote the growth of traffic. According to Cisco forecast (CISCO, 2013), mobile data traffic will have a 13-fold increase between 2012 and 2017. In addition, due to the rapid development of wireless communication technology, the wireless transmission rate comes into a new stage. The LTE provides the peak rate of 100 Mbit/s in downlink and 50Mbit/s in uplink (3GPP, 2005) which arouses users intense interest for better user experience. However, the current access networks can not provide sufficient capacity for such a traffic surge. Therefore, it is imperative for the researchers to find effective solutions that can handle the critical problem.

As new smart devices already can support for multi-interfaces access, the increasing previous study has focused on using WLAN to offload traffic from both 3G and LTE. Firstly, WLAN is a promising candidate for its cheap price, easy-to-deploy and high data transmitting speed (Yang *et al*., 2013). Secondly, because about seventy percent of the mobile traffic generates indoors, WLAN has great potential for reducing the traffic overload. Furthermore, compared with the LTE network, WLAN provides higher speed but lower mobility and coverage. Hence, the two networks have complementary performance (Kim *et al*., 2013).

Several recent research efforts have focused on offloading cellular traffic to WLAN networks. Authors (Lee *et al*., 2010; Dimatteo *et al*., 2011; Balasubramanian *et al*., 2010) introduce the offloading feasibility and quantitative study on the performance of 3G mobile data offloading through WiFi networks. However, all the researches assume that WLAN has enough free capacity to provide ideal QoS without taking the dynamics and bidirectionality of traffic offloading into consideration. Zhuo *et al*. (2011) proposes an incentive framework about 3G traffic offloading by shifting the traffic with high delay tolerance to WLAN. But this method cannot handle with delay-sensitive traffic. In Bennis *et al*. (2013), traffic is controlled to offload by

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using multimode small cell base stations with a cross-system learning method. But once traffic steers to WLAN, the operators lose control of users and cannot deliver any network service to them. Therefore, it is necessary to control the overlay networks with LTE and WLAN in a centralized manner. Moreover, the real-time network status and self-adaptive offloading are also key factors in offloading area.

This study proposes a novel approach to offload traffic adaptively in accordance with the dynamic network which is combining Open Wireless Network (OWN) with a biological selection algorithm named attractor selection. The OWN is an implementation of Software Defined Network (SDN) in radio access network. Firstly, the OWN is used to provide global centralized control over the subscribers (including control the users and deliver subscribe content to them), manage traffic flexibly and build a situation-aware service. Secondly, we use a novel packets arrival process to obtain the real-time network status of LTE and WLAN, respectively. In addition, attractor selection is adopted for the User Equipment (UE) to select the most suitable access network. Based on the global control under OWN and autonomous decision of attractor selection, the whole wireless network can be managed in an autonomous, load balancing and robust manner. The objective of this study is to provide an effective solution for adaptive traffic offloading based on the real-time network status.

MATERIALS AND METHODS

System model analysis: A novel open architecture is proposed here to make cooperation between LTE and WLAN networks. Meanwhile, it determines whether the traffic offloading should be performed according to the current state.

The OWN is introduced in the system under consideration to provide a global control over the subscribers, build a situation-aware service and manage traffic flexibly. It is the implementation of SDN in the radio access network including LTE, 802.11WLAN, etc. (Wang *et al*., 2013).

As the architecture shown in Fig. 1, the system works in the radio access network and it needs no modification of core network or backhaul network. Similar with some SDN frameworks, OWN makes a separation of control plane and data plane. The system involves a cloud-based controller, protocols including southbound and northbound and a programmable data plane. The Base Stations (BS) and Access Points (AP) based on software, such as LTE eNodeBs, WLAN APs, work as the programmable data plane and they are connected to the controller by southbound protocol. The control plane, which is the heart in the whole architecture consists of Operating System (OS) running on a cloud-based controller and various applications connected to OS by northbound protocol. According to the requirements of operators, the different applications can be added to the OS by open Application Programming Interfaces (API). In this study, three main kinds of applications (situation-aware, vertical handover and attractor selection) are adopted to realize traffic offloading adaptively. The function of situation-aware is that the controller can obtain the situation message of all the BSs and APs such as location information, traffic load, service type and so on. Based on the above information, the controller can handover flexibly and keep load balancing among heterogeneous networks by vertical handover application. To decrease excessive overheads in the controller resulting from frequent signaling interaction between the control plane and the data plane, we propose the attractor selection as the application in control plane to provide an adaptive traffic offload and then decrease the burden of the controller.

The overlay network system model with LTE and WLAN is considered in this study. The LTE eNodeB is located in the center of the cell and several WLAN APs randomly distribute in the overlay area. Once UEs enter the overlapping area, they can select either LTE eNodeB or WLAN APs around for access under the control of OWN.

Every time new traffic business requests access to LTE, the controller run the situation-aware to find out whether if practicable WLAN APs existing around. Because the controller can obtain the information of all the BSs/APs connected to it, researchers can utilize the open API to make the attractor selection running on OS. By adaptive selection based on the real-time base station information of the LTE and WLAN, if the situation of LTE can satisfy the current traffic need, the access keeps in the LTE so that unnecessary consumption is reduced. If not, the nodes can select the candidate WLAN network to acquire better Quality of Service (QoS). Considering the session continuity, the enhanced non-seamless method can be considered (Yoon and Jang, 2013) to reduce handover delay as far as possible. Attractor selection will be explained in the following section.

Adaptive traffic offloading method: In this section, an adaptive traffic offload method based on attractor selection is proposed to select the suitable access network in a fluctuant environment and the basic behavior of the proposal according to the real-time network states is described.

Attractor selection model for adaptive traffic offloading: Attractor selection model is presented firstly to describe

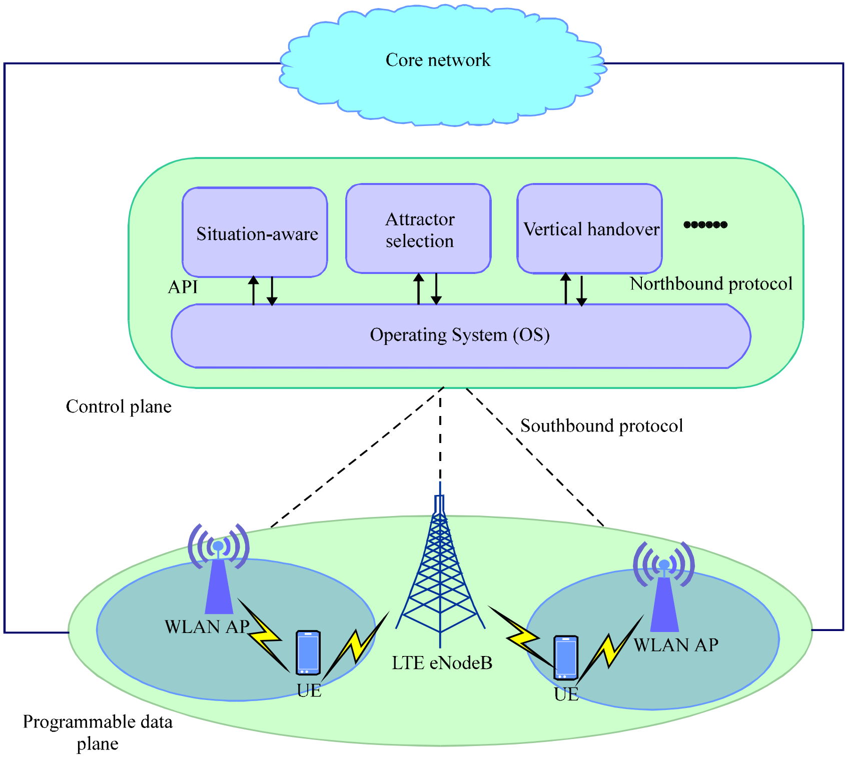

Fig. 1: System architecture makes a separation of control plane and programmable data plane in radio access network, (1) the control plane consists of Operating System (OS) running on a cloud-based controller and various applications (situation-aware, attractor selection and vertical handover) connected to OS by northbound protocol, (2) Software-based base stations or access points (BSs/APs), such as LTE eNodeBs, WLAN APs and so on, work as the programmable data plane. Once UEs enter the overlay area, they can always access to the appropriate network under the control of OWN

that the host *Escherichia coli* (*E. coli*) cells could adapt to changes in the availability of two nutrients by utilizing noise (Kashiwagi *et al*., 2006). In this model, the stable states of host *E. coli* cells in a process of metabolism are called attractors and it introduces the term called activity reflecting the fitness of a cell in the current environment. Due to introducing random noise and self-feedback mechanism, attractor selection can provide good robustness and noise-tolerance performance.

This study presents a two-dimensional attractor selection model to achieve traffic offloading in overlay network. The mathematical model is as follows:

$$\frac{dm_1}{dt} = \frac{S(\alpha)}{1+m_2^2} - D(\alpha)\times m_1 + \eta_1$$
$$\frac{dm_2}{dt} = \frac{S(\alpha)}{1+m_1^2} - D(\alpha)\times m_2 + \eta_2 \qquad (1)$$

And:

$$S(\alpha) = \alpha\times(\beta\times\alpha^{\gamma} + \varphi^{*})$$
$$D(\alpha) = \alpha \qquad (2)$$

where, m_1 and m_2 are called network state values and is defined as activity. The functions and rate coefficients of synthesis and degradation, respectively and both are increasing functions of α. The parameters β and γ are factors which influence the stability of attractors and the speed of convergence, φ* is a constant for the dynamic system to have stable attractors (Leibnitz *et al*., 2007). In addition, η (i =1 or 2) is the Gaussian noise inherent in the whole system which is independent of the activity α.

For convenience, we set:

$$\phi(\alpha) = S(\alpha)/D(\alpha) \qquad (3)$$

By setting Eq. 1 without noise, i.e., $dm_i/dt = 0$, i = 1or i = 2, as if $\phi(\alpha) > 2$, one can get the equilibrium $m_1 = 1/m^*$ and $m^2 = m^*$ or $m_2 = 1/m^*$ and $m_1 = m^*$ i.e., the model has two attractors, $m_1 >> m_2$ and $m_1 << m_2$. However, if $\phi(\alpha) \le 2$, the system will get an unstable steady-state $m_1 = m_2$. In order to make a selection after the system settles out, φ* is set as 2.

If the value of α is large, it means the Current Access Network (CAN) can satisfy the traffic demand. It is unnecessary to perform handover to another candidate network and CAN will be the suitable selection. In attractor selection model, it represents the system converges to an attractor and the basin becomes deeper, so that the force of maintenance of the attractor is strong. If the value of α is small, it means the condition of CAN is poor. Thus, the stochastic noise dominates the system to leave the current basin easily and walk randomly. Until walking to a new appropriate attractor, the system becomes stable and the determinant mode controls the system again.

For example, with the initial state is $m_1 >> m_2$, it means that new traffic demand in the overlay area always chooses LTE to transmit data, at the same time, the system statically stays in an attractor. Now, assuming that the status of LTE becomes worse suddenly, it leads to the decay of α, so that the noise term dominates the system. For the current situation, the traffic access to LTE previously switches to WLAN or more new traffic chooses the latter autonomously which leads to $m_1 < m_2$. Since WLAN can provide better QoS in the current condition, the activity begins to increase until the system gets rid of random fluctuation and reaches the new attractor $m_1 << m_2$.

Overall, the definition of activity is crucial for the whole model, so the next subsection will mainly discuss the derivation of activity.

Derivation of actitvity: The value of activity is derived by the temporal differential equation as follows:

$$\frac{da}{dt} = \delta(\alpha^* - \alpha) \tag{4}$$

where, δ is the rate of adaptation of α, α^* is the instant activity.

To simplify principle, we take three discrete values to define α^* based on the condition of current access network:

$$\alpha^* = \begin{cases} 1 & \tau_{cp} - \min(\tau_1, \tau_2) = 0 \\ 0.7 & 0 < \tau_{cp} - \min(\tau_1, \tau_2) < \Delta \\ 0 & \tau_{cp} - \min(\tau_1, \tau_2) \geq \Delta \end{cases} \tag{5}$$

where, τ_{cp} is the delay of current access network and τ_1, τ_2 are the delay of LTE and WLAN, respectively which reflect the real-time environmental situations and QoS of the overlay networks. Firstly, when the value of τ_{cp} is minimum, it means that the condition of current network shows ideal and the capacity is enough to undertake the subsequent access requirement. Therefore, $\alpha^* = 1$ is used to represent the highest activity. The second situation $\alpha^* = 0.7$ signifies that the current choice is not optimal and the system is affected by noise but it still can satisfy the current traffic management and provide necessary QoS. Therefore, the controller will maintain current connection and operates local adjustment such as allocate more resources to the current network or control the subsequent traffic request to connect to the other network. In addition, when the difference between the current delay and the minimum value exceeds the threshold Δ, the activity rapidly approaches zero due to the poor condition of current network. Then, the whole system is dominated by random noise and the research to a new attractor. Finally, it automatically switches to the candidate network to recover service.

To describe the real-time status of the networks, this study obtains delay τ with the calculation model depending on a packet arrival process modeled by dMMPP. For more general than traditional Poisson Mode, the dMMPP is able to capture burstiness in traffic arrival process (Xu *et al*., 2008). In this model, we define l as the number of packets in the queue, $0 \leq l \leq L$ and m is the number of packets arrival to the queue, $0 < m \leq M$. Furthermore, $v_{(l,m)}$ is the stationary probability, representing that the queue has l packets and the number of arrival packets is m.

Based on the Little's Theorem, the average delivery delay is calculated as:

$$\tau = \frac{\overline{n}_{wait}}{\overline{\lambda}(1 - P_{drop})} \tag{6}$$

To obtain the delivery delay, we should derive three terms, i.e. the average packet arrival rate $\overline{\lambda}$, the average number of packets waiting in the queue $\overline{n}_{wait}$ and the packet dropping probability P_{drop}.

Let U be the transition probability matrix of the modulating Markov chain. The $\mu U = \mu$ and $\mu e = 1$, where μ is the stationary probability of matrix U and e is a column matrix of 1. When the number of packets arrival is m, we can use U_m to represent the arrival rate matrix. The U_m is derived from:

$$U_m = \begin{pmatrix} f_m(\lambda_1, T) & & 0 \\ & \ddots & \\ 0 & & f_m(\lambda_S, T) \end{pmatrix} \tag{7}$$

$$f_m(\lambda_S, T) = \frac{e^{-\lambda_S T}(\lambda_S T)^m}{m!} \tag{8}$$

The $f_m(\lambda_s, T)$ means that in a time slot T, m packets have arrived to the queue with an arrival rate λ_s which complies with the Poisson distribution.

The probability of m packets arrival can be obtained from:

$$F_m = \mu U_m e \tag{9}$$

Then, the mean arrival rate can be calculated as:

$$\bar{\lambda} = \mu \sum_{m=0}^{M} U_m e \tag{10}$$

With the stationary probability representing the queue has l packets and the number of arrival packets is m, i.e., $v_{(l,m)}$, the average number of packets waiting in the queue can be obtained as:

$$\bar{n}_{wait} = E(n_{wait}) = \sum_{l=0}^{L} l\left(\sum_{m=0}^{M} v_{(l,m)}\right) \tag{11}$$

Assume that there are l packets in the queue at the beginning and then m packets arrive in a time slot T, the number of dropped packets is calculated from:

$$n_{drop} = \begin{cases} (l+m) - L & m+l > L \\ 0 & m+l \le L \end{cases} \tag{12}$$

Based on Eq. 12, the average number of dropped packets per time slot comes from:

$$\bar{n}_{drop} = E(n_{drop}) = \sum_{l=0}^{L} \sum_{m=L-l+1}^{M} (l+m-L) v_{(l,m)} \tag{13}$$

So, we can obtain the packet dropping probability as:

$$P_{drop} = \frac{\bar{n}_{drop}}{\bar{\lambda}} = \frac{\sum_{l=0}^{L} \sum_{m=L-l+1}^{M} (l+m-L) v_{(l,m)}}{\mu \sum_{m=0}^{M} U_m e} \tag{14}$$

Based on Eq. 10, 11 and 14, the delivery delay of LTE and WLAN can be gotten, respectively, i.e. τ_1 and τ_2 as follows which can be used to obtain activity:

$$\tau = \frac{\sum_{l=0}^{L} l\left(\sum_{m=0}^{M} v_{(l,m)}\right)}{\mu \sum_{m=0}^{M} U_m e\left(1 - \frac{\sum_{l=0}^{L} \sum_{m=L-l+1}^{M} (l+m-L) v_{(l,m)}}{\mu \sum_{m=0}^{M} U_m e}\right)} \tag{15}$$

RESULTS AND DISCUSSION

This section evaluates the performance of the proposed method using attractor selection for offloading by simulation experiment. Assuming that attractor selection keeps running in the application layer, the controller operates the algorithm to calculate delay and activity α from the transfer message in the data plane.

On-the-spot offload (Yang *et al*., 2013; Balasubramanian *et al*., 2010; Pyattaev *et al*., 2013) and greedy algorithm (Zhuo *et al*., 2011; Roy *et al*., 2006) are conventional methods to offload traffic. To better analyze the impact of the proposed method on the overlay network, the performances of the proposed methods are compared with that derived by those two conventional methods in adaptability and robustness. The simulation assumption of overlay networks is described in Himayat *et al*. (2014).

Numerical results of the average delay: We adopt the two-phase dMMPP model for packets arrival process to simulate the delay of LTE and WLAN networks, respectively. As the initial condition, the parameters are set as:

$$U = \begin{pmatrix} 0.6 & 0.4 \\ 0.6 & 0.4 \end{pmatrix}, \lambda = \begin{pmatrix} 5 & \\ & 15 \end{pmatrix}$$

Based on the typical region $p_{per} \subseteq [10^{-4}, 10^{-1}]$, we assume P_{per} as stochastic process with the mean value and variance express as $(4.5, 1.5)^* \, 10^{-3}$ and $(3, 0.6)^* \, 10^{-3}$ and the delay of LTE and WLAN could be obtained as shown in Fig. 2. In addition, Fig. 2 compares the average delay of

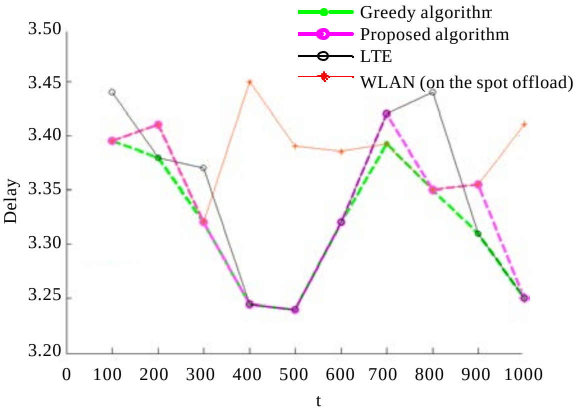

Fig. 2: Average delay of LTE, WLAN (on-the spot offload), greedy algorithm and proposed method. Each line shows time variation of delay under different traffic allocation

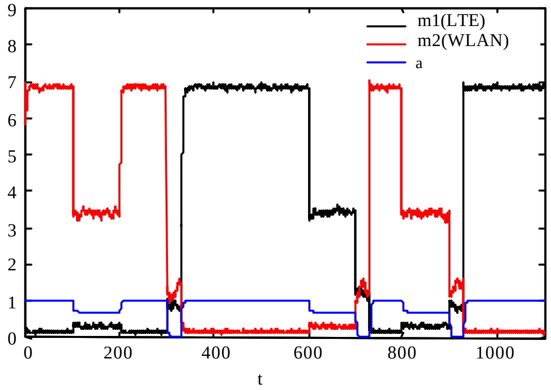

Fig. 3: Time variation of state value (m_1, m_2) and activity α. At time t = 300, the condition of WLAN is falling badly and the system starts to lose the activity which destabilized the selected network WLAN. The system is fluctuating along with the stochastic noise to search the new balance in (300,320). At time t = 320, the system choose the appropriate network (LTE). Similarly, at time t = 700 and 900, the system offloads traffic adaptively to the better network according to the fluctuating environments

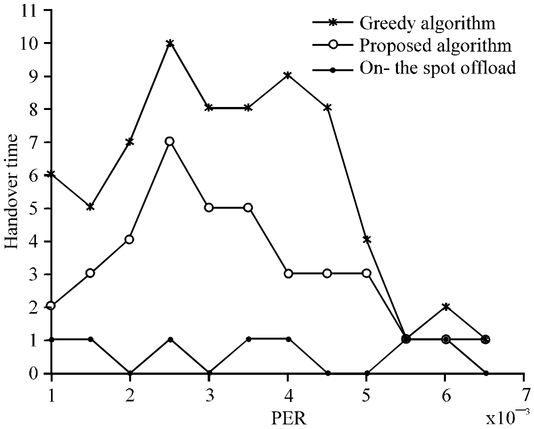

Fig. 4: Handover times of Greedy algorithm, on-the-spot offload and proposed method

on-the-spot offload, greedy algorithm and proposed method. On-the-spot offloading is the red solid line coinciding with WLAN delay line. As shown in the figure, although, the delay of proposed scheme based on attractor selection, i.e., ATOM is not always the minimum value among four schemes, its performance is much better than on-the-spot offload. Additionally, the difference between ATOM and the optimal is smaller. On-the spot offloading means users connect to WLAN and transfer data on the spot as long as there is a WLAN available access point around.

Activity and network state values: In order to verify the adaptability of the system, (τ_1, τ_2) is obtained at every 100 points. The activity and network state values are tested at every 30 points. In Fig. 3, the dynamics of two network state value is shown in red and black line, respectively. In addition, α is indicated in blue lines.

Before t = 300, the mobile traffic always chooses WLAN for transmission because of its lower delay at first. Although, the network condition is changing and the delay of WLAN is larger than LTE sometimes, the difference is not so large to trigger stochastic mode in attractor selection so that UE keeps in WLAN. When t = 300, the condition of WLAN is falling badly and the activity is closing to zero. The system is fluctuating along with the stochastic noise to search the new balance in (300,320). The new access request is allocated to LTE and the activity recovers. Similar changes also happened in (700,720) and (900,920). When the current network is the optimal choice or within the scope of the threshold value, the controller will not perform vertical handover which can reduce signalling overload and ensure traffic demand at the same time. When the delay of current access network exceeds the required threshold, traffic will be offloaded to the other network adaptively.

Comparison of Robustness: The handover times among on-the-spot offload, greedy algorithm and the proposed method are compared in Fig. 4. Obviously, the handover time of on-the-spot offload is the least because UE will switch to WLAN spontaneously if the AP around is available. With the greedy algorithm, users tend to choose the best network with the minimum delay. However, it will lead to frequent network handover while the proposed method can adapt to the suboptimal choice within the threshold, so the handover time is less than greedy algorithm. The presented method is suboptimal and the less handover times, the more robust the system is. Considering the comparison of delay above, the proposed mechanism can reach a tradeoff between the system delay and the handover times, so it can not only guarantee target QoS but also reduce ping-pong's effect and keep the network robust.

CONCLUSION

In this study, a novel dynamic system has been proposed to offload traffic between LTE and WLAN. It is based on OWN architecture and the biological attractor selection model which not only keeps adaptive to the fluctuations in the environment but also owns global control ability by the controller. This method proves feasibility and good performance through simulating the delay and the handover times under the actual scenario. No matter how the environment changes, the traffic demand can be always satisfied and the system makes a robustness manner. Our future study will focus on applying the method to multidimensional system and considering offloading competition among multiple WLAN APs.

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