## RESEARCH

**Open Access**

# Enabling location-aware quality-controlled access in wireless networks

Hwangnam Kim[1*], Hyun Soon Kim[1], Suk Kyu Lee[1], Eun-Chan Park[2] and Kyung-Joon Park[3]

**Abstract**

Location-based services (LBSs), such as location-specific contents-providing services, presence services, and E-911 locating services, have recently been drawing much attention in wireless network community. Since LBSs rely on the location information in providing services and enhancing their service quality, we need to devise a framework of directly using the location information to provide a different level of service differentiation and/or fairness for them. In this paper, we investigate how to use location information for QoS provisioning in IEEE 802.11-based Hot Spot networks. Location-based service differentiation is different from existing QoS schemes in that it assigns different priority levels to different locations rather than flows or stations and schedules network resources to support the prioritized service levels. In order to realize such the location-based service differentiation, we introduce the concept of *per-location target load* to simply represent the desirable rate of traffic imposed to the network, which is dynamically changing due to the number of stations. The load consists of *per-location load*, which directly quantifies per-location usage of link capacity, and *network-wide load*, which indirectly calibrates the portion of *per-location load* contributed to the network-wide traffic. We then propose a feedback framework of provisioning service differentiation and/or fairness according to *per-location target load*. In the proposed framework, the load information is feedback to traffic senders and used to adjust their sending rate, so that per-location load does not deviate from a given per-location share of wireless link capacity and lays only tolerable traffic on the network in cooperation with other locations. We finally implemented the proposed framework in *ns-2* simulator and conducted an extensive set of simulation study so as to evaluate its performance and effectiveness. The simulation results indicate that the proposed framework provides location-based service differentiation and/or fairness in IEEE 802.11 Hot Spot networks, regardless of the number of stations in a location, traffic types, or station mobility.

**Keywords:** Service differentiation, location-based service, IEEE 802.11, Hot Spots

## 1 Introduction

With portable WiFi-enabled laptops and PDAs, cost-effective installment of access points (APs), the license exempt bands, and timely available international standards, IEEE 802.11 wireless local area networks (WLANs) [1] have been widely deployed in order to provide pervasive access to the Internet for nomadic people. In addition to these last-mile extensions in campuses, restaurants, and convention centers, IEEE 802.11-enabled portable consumer electronics have also started to be available in home networks for uploading and/or downloading multimedia contents to/from a home gateway.

On the other hand, wireless Internet service providers (WISPs) recently implemented and launched location-based services (LBSs) owing to the availability in location measurement technologies and the noticeable advancements in personal navigational aids and tracking services [2-4]. LBS gives WISPs the ability of tailoring available information and services to user's preference based on his (or her) current location and also of providing location-specific control and management for themselves to conduct efficient network resource management. Additionally, it comes into play in public safety and security since the 911 mandate of U.S. Federal Communication Committees requires the location of a

* Correspondence: hnkim@korea.ac.kr
[1]School of Electrical Engineering, Korea University, Anam-Dong, Seongbuk-Gu, Seoul 136-713, Korea
Full list of author information is available at the end of the article

wireless station should be available for emergency call dispatchers [5]. LBSs are usually deployed in an integrated framework of positioning technology, personal devices of displaying geographic information, and location-specific information system in order to support various types of applications (available at a designated location). Based on the framework, LBS (*i*) enables users to pinpoint their current position in a new area into which they move or to search geographical information in the position; (*ii*) personalizes information, contents, or services according to users' interest; (*iii*) provides a list of local service providers for users according to their location, e.g., private location, home location, or work location, so that they can choose one of them giving most economic rate for voice or data service, i.e., at rate, special, and discount rate; (*iv*) assists users to determine most appropriate communication access technology, such as cellular, WiFi, WiMAX, or BlueTooth; (*v*) identifies emergent events or users in danger or disseminates crucial events to all the people in the proximity and then provides the relevant safety services and information; (*vi*) provides privileged access to keep track of friends, family members, or employees moving in a fleet. Considering LBSs directly use location information and also require different levels of quality of services (QoS), we need to use the location information in LBS frameworks in order to provide QoS for LBSs, instead of just resorting to any existing per-flow or per-station QoS-provisioning scheme [6-24].

In this paper, we propose a framework of service differentiation to support LBSs in IEEE 802.11-based Hot Spot networks. For example, if we assume that a conference or class room is equipped with a Wi-Fi AP to let all the participants to share presentation or class materials, which usually covers a few tens of square meters, then a presenter or instructor gives a presentation with his handheld Wi-Fi devices (such as PDA or notebook), whose traffic is upload traffic to a web disk (or a cyber bulletin board) and attendants or students listen to the presentation with their devices, whose traffic is download traffic from the disk. In this configuration, upload and download traffic are decided by the location at the room. Note that the position for the presenter or instructor is usually in the front area of the location. Since this kind of configuration can be possible wherever the position determines the traffic direction and quality, we need to devise location-aware service differentiation scheme for Hot Spot networks.[a] Note that since the techniques for identifying a correct position achieve 90% of accuracy within roughly 2 m [25], LBSs and their differentiations need to realized with the same accuracy, and Hot Spot networks, which usually covers a few tens of square meters, are large enough to accommodate those differentiations.

Even though there are some solutions to support QoS, such as IEEE 802.11e [24], they are not appropriate for the service differentiation for LBSs, i.e., *provisioning different level of service qualities according to user's current location*, since they just focus on per-flow or per-station QoS enforcement without considering and exploiting location information. within a LBS framework, Therefore, we need to take a departure from the per-flow or per-station QoS-provisioning schemes (which are explained in Section 2) and then propose a new aspect of service differentiation, *location-aware QoS provisioning*, in IEEE 802.11 Hot Spot networks. In other words, we propose to *assign per-location priority (or weight) instead of per-station or per-flow* to the traffic, regardless of the number of stations at a location, traffic types, station mobility, or wireless link status. The proposed scheme operates in what follows. It first partitions the AP coverage into several locations, various from a single point to a region[b], and then assigns a different weight to each location. Then, AP continuously keeps track of load (network-wide and subnetwork-wide) and feedbacks the information to traffic senders. Traffic senders then adjust their sending rate according to the delivered load information. Note that traffic senders are assumed to be TCP senders in this paper, but if traffic senders can use some feedback control function, then the proposed scheme can be applied to them also. We implemented the framework in *ns-2* simulator and carried out an extensive set of simulations to evaluate its performance with respect to service differentiation. The simulation results indicate that the framework provides per-location service differentiation and fairness, regardless of the number of stations per region, station mobility, traffic types, wireless link errors, and any combination thereof. Note that the AP is assumed to know all the stations' positions within its coverage. This is possible with GPS or any other positioning device and/or infrastructure. In the cases where GPS is unavailable, we can estimate the direction and position of transmitting node since we have some techniques for estimating them. The standard way of doing this is by using more than one directional antenna [26]. Specifically, the direction of incoming signals is determined from the difference in their arrival times at different elements of the antenna. To the best of our knowledge, this is the first attempt to exploit location information to provide a service differentiation in IEEE 802.11-based Hot Spot networks. We believe that the proposed scheme is very appropriate for providing a QoS scheme for LBSs in wireless networks and also used to extend previous per-flow or per-station QoS frameworks.

The rest of the paper is organized as follows. We first summarize previous work related to LBSs and the service differentiation schemes devised in WLANs in

Section 2 and then we explain the motivation for this work with an example in Section 3. We propose a framework of QoS provisioning in Section 4, validate the framework in Section 5, and present the simulation results in Section 6. Finally, we conclude the paper with Section 7.

## 2 Related work

In this section, we summarize LBSs and QoS-provisioning schemes in WLANs prior to proposing a location-based service differentiation scheme. As for service differentiation, we include work that deals with fairness among wireless stations as a sub-category of service differentiation since the fairness scheme can be extended to provide weighted-fairness with acceptable modification and the weighted-fairness scheme can be regarded as a kind of service differentiation.

### 2.1 Location-based services

Once the first commercial LBSs were launched in Japan by KDDI in 2001, mobile network service providers have started to pay much attention to exploiting geographical information to provide users with services tailored to their specific location or to assist them to achieve their objective at the location [27] (e.g., traffic routing). Additionally, since the E-911 mandate obliges cellular service providers to be able to pinpoint the source of emergency call [5], many researches and developments have been made to realize LBSs.

In overall, LBS relies on an integrated framework of positioning technologies, coordinate system, geographic information system, and applications. Among those constituents, improving positioning technologies in perspective of the quality of positioning (the accuracy of localization) have been addressed with high priority and then a city-wide framework of provisioning location-based applications and services, such as LoCation Service (LCS), navigation services, intelligent traffic alerts, tracking, pinpointing child's location, and local map provisioning have been dealt with much attention in the community [2-4]. Noticeable point is that these research and developments are guided by the international standard organization, such as ITU-the 3rd Generation Partnership Project (3GPP) [28], ITU-the 3rd Generation Partnership Project 2 (3GPP2) [29], Open Mobile Alliance (OMA) [30], and Internet Engineering Task Force (IETF) [31].

As mentioned earlier, LBS can be successfully implemented and deployed with the following principal attributes. *Firstly*, the positioning technologies have been playing a key role to realize LBS and have been proposed in various ways. We can estimate one person's current location based on (*i*) a combination of previously known locations, moving speed, and an identified course; (*ii*) pre-established base station coordinates or cell ID (base station ID); (*iii*) a trilateration based on signal strength, time of arrival, and angles of arrival analysis; (*iv*) a Global Navigation Satellite System, such as global positioning system (GPS), assisted-GPS (A-GPS), and Galileo System. *Secondly*, in addition to these positioning technologies, location management has also been developed in cellular networks to support paging, roaming, and handover. *Thirdly*, both the positioning and location management are carried out within a coordinate system. We have a number of coordinate systems, e.g., universal transverse Mercator (UTM), military grid reference system (MGRS), National Grid Systems, Irish National Grid, and any other global or local coordinate system [32]. *Fourthly*, the geographic information system (GIS), which is an information system that processes geographic data, plays also important role in deploying LBSs since many features of GIS should be used to enhance service quality of current LBSs or develop more advanced LBSs [33]. *Lastly*, we should develop various applications to which LBSs are applied to (*i*) smart communication, which chooses an appropriate access technology available in a specific location and/or suitable to satisfying delay or throughput constraints for communication services, (*ii*) efficient fleet control and management which locates and keeps track of mobile vehicles and their performance at regular intervals, (*iii*) intelligent navigation system which allows mobile vehicles to avoid traffic congestion and to warn of diversions, traffic accidents, and any other emergent situation, (*iv*) enhanced safety and security, which saves people from emergent accidents, weather, and natural disaster, and (*v*) location-dependent entertainments which are location-based directory services, peer-to-peer contents sharing localized to a certain area, location-specific instant personal messaging, and etc [34]. We do not discuss aforementioned issues further since they are out of scope of this paper,

**Remark:** Most of the previous work do not directly address the quality of services (QoS), but instead, resort to existing research that partially deals with QoS provisioning within its target system, such as network, operating, multi-media, and real-time system. However, considering that every LBS exploits location information, has different requirements, and processes location itself as one of attributes to define the services, we need to directly use location information within a LBS framework in order to provide *location-based service differentiation*.

### 2.2 Service differentiation in WLANs

In this section, we succinctly explain previous work to provide fairness and/or service differentiation in IEEE 802.11-operated WLANs.

As the first category of service differentiation or fairness, there are some schemes that directly control TCP congestion window size so as to mitigate the unfairness issue of TCP in IEEE 802.11 MAC protocol [6,7]. Pilosof et al. [6] have exhibited that the AP in a Hot Spot network favors uplink TCP flows more than downlink TCP flows and its buffer capacity affects the fairness among stations, and then proposed the solution that the AP directly manipulates the advertised TCP window size included in TCP acknowledgment (ACK) packets passing through it. Lee et al. have proposed the solution of extending the idea in [6] in the way that AP modifies advertised TCP window size by reflecting a maximally achievable TCP window size into the computation of advertised window size in addition to inspecting current buffer availability [7].

As the second category, queue management schemes have been proposed to address the fairness in IEEE 802.11 WLAN [8-12]. The approach presented by Wu et al. is to carry out per-flow scheduling at the AP in the way that it distinguishes data queue type from ACK queue type and computes to use optimal scheduling probability for each flow queue [8]. Similarly, Lin et al. have proposed to use a queue management scheme where AP maintains virtual per-flow queue and makes separate packet-dropping probability based on each queue length [9]. Ha et al. have presented a dual queue scheme, one of which is used for TCP data and the other is for TCP ACK. The scheme schedules each queue with different scheduling probability to achieve per-flow fairness [10]. Gong et al. have proposed to employ SPM-AF (selective packet marking scheme with ACK filtering) scheme and combine it with LAS (least attained service) scheduling [11]. This approach focuses on assuring per-flow fairness by giving much service opportunity to downlink TCP data packets; the AP removes redundant ACK packets belonging to the same connection when they arrive in the queue. Nicola et al. mitigates the unfairness problem by implementing a token-bucket-based rate-limiter in the AP. The limiter controls the rate of aggregate uplink traffic in the manner that it provides fairness between downlink and uplink TCP flows [12].

As the last category, there exists some solutions that directly differentiate channel access schemes [13,14]. Leith et al. employed the service differentiation scheme of IEEE 802.11e [24] to achieve the fairness. In the scheme, a different set of inter-frame space, contention window size, and transmission opportunity (TXOP) is specified and applied to TCP data and ACK packets [13]. Bruno et al. have exploited frame bursting to improve TCP fairness between uplink and downlink flows and to maximize channel utilization. In the approach, AP is able to transmit multiple frames in a burst, whose size is adjusted based on the collision probability monitored in the AP [14]. Additional schemes of supporting the fairness among sending and receiving stations directly manage MAC parameters in [15-17]. The approach in [15] mitigates the unfairness by reducing the chances of transmission for the sending stations in the way of increasing the minimum contention window size. The downlink compensation access (DCA) algorithm in [16] gives higher priority to the AP with smaller inter-frame space. In the proposed method of [17], each sending station defers its access based on the next packet information.

**Remark:** As mentioned in Section 1, the scheme that we propose in this paper has a different aspect from aforementioned methods in that it assigns a different priority (weight) to a different location according to the required service quality, instead of flow and station. The proposed scheme can also resolve in part the unfairness between uploading and downloading stations, and additionally, it can be incorporated into any service differentiation scheme aforementioned.

## 3 Motivation: location-aware service differentiation

Before we propose the framework for provisioning location-aware QoS, we demonstrate that the current IEEE 802.11-based Host Spot networks are inappropriate for supporting location-based service differentiations.

Suppose we have the network presented in Figure 1 where Region-1 has one station, which is denoted by DN STS and carries out bulk download with FTP traffic, and Region-2 has another station, which is denoted by DN STS and also generates download FTP traffic during the whole time of [0s, 160s]. Additionally, the Region-1 comes to have the third station at the instant of 40s, which is denoted by UP STS and active to conduct upload FTP traffic during the next 80s. The main problem that we address in the paper is how to
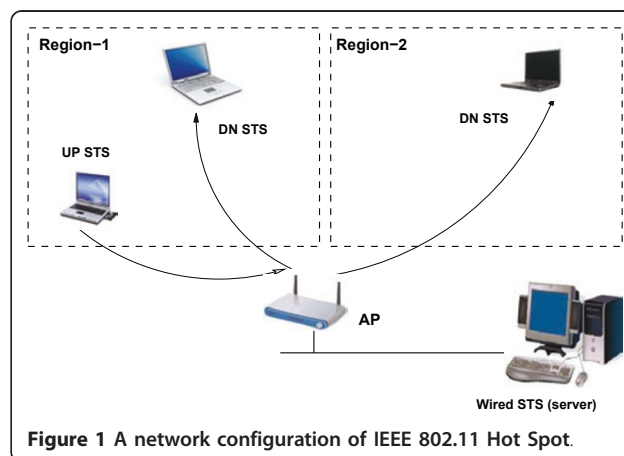


**Figure 1 A network configuration of IEEE 802.11 Hot Spot.**

serve an equal amount of data delivery service to `Region-1` and `Region-2` or to give a higher priority to the station at `Region-2` than any station at `Region-1`, regardless of the number of stations per region, traffic types generated at each station, station mobility, or wireless link errors. Therefore, if we let the aggregate throughput at `Region-1` equal to that at `Region-2`, we can give a higher priority to `DN STS` at `Region-2` than any other station at `Region-1` and also achieve fairness between two regions. Note that "*the aggregate throughput*" means the summed result of all the throughput achieved at each station in the same region. Figure 2 presents the results obtained when we use existing IEEE 802.11 MAC protocol. From the figure, we observe the followings. *Firstly*, IEEE 802.11 DCF cannot guarantee any service differentiation nor fairness even among stations. Specifically, we observed (*i*) in the period of [0s, 40s], each region has only one station active, and `DN STS` at `Region-1` uses 2.16 Mb/s while `DN STS` at `Region-2` does 2.06 Mb/s; (*ii*) in the period of [40s, 120s] when `UP STS` appears at `Region-1`, the throughput of `DN STS` at `Region-1` is degraded to 0.73 Mb/s while that of `DN STS` at `Region-2` is decreased to 0.97 Mb/s, but `UP STS` at `Region-1` gains the higher throughput of 2.76 Mb/s; (*iii*) in the last period of simulation, which is [120s, 160s], `DN STS` at `Region-1` uses 2.74 Mb/s while `DN STS` at `Region-2` does 1.64 Mb/s. *Secondly*, IEEE 802.11-based network imposes unfairness on downloading stations (two `DN STSs`) compared to uploading station (`UP STS`) due to TCP-driven unfairness exaggerated with IEEE 802.11 DCF [35-37]; *Lastly*, there is no location-based service differentiation. Note that the aggregate throughput of `Region-1`, which is the summed throughput of two stations, is 3.49 Mb/s, but that of `Region-2`, which is simply the throughput of `DN STS`, is 0.97 Mb/s (during the period of [40s, 120s]).



**Figure 2 Throughput usage in 802.11**.
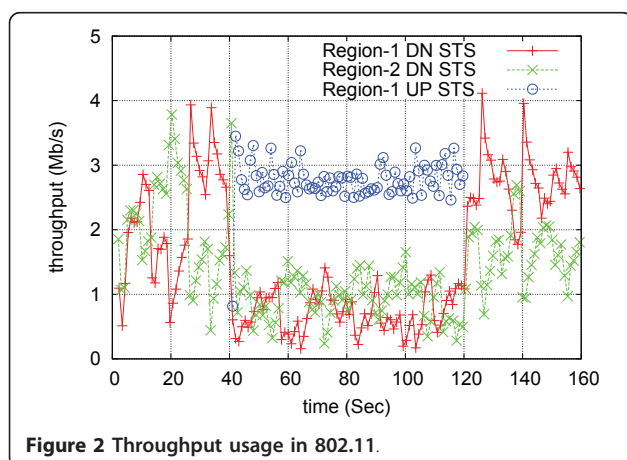
## 4 Service differentiation algorithm based on per-location load

In order to compute the portion of link capacity assignable to each location for location-based service differentiation, we introduce `per-location target load`. The load represents a desirable degree of traffic that a designated location imposes to the network (to the AP); it is used to match the aggregate input rate across all the stations in the location with the given portion of link capacity previously assigned to the location. Note that the "*aggregate input rate*" means the total summed rate of all the traffic imposed on the AP. Considering that the capacity of wireless channel and network-wide load are time-varying due to the varying number of contending stations, we cannot deterministically decide the optimal target per-location load (which lets the aggregate input rate to match with the per-location link capacity). Therefore, we need to adjust the *current* input rate to the *current* per-location link capacity, so that we devise `per-location target load` to provide per-location weighted fair share of link capacity.

This load information is estimated by `TaLE`, which stands for target load estimator and positioned at the link layer of AP, then delivered to traffic senders, and finally used to let them to adjust their sending rate. In specific, the `per-location target load`, denoted by $\omega_i$, for the *i*th location $R_i$ consists of two portions: (*i*) the `per-location load`, $\omega_i^r$, (*ii*) the `network-wide load`, $\omega_i^\ell$, where the former represents per-location link usage (in the influence of wireless link errors) and the latter represents the contribution of `per-location load` to the network-wide load (affected by the number of stations across the all the regions). The `per-location target load` is denoted as:

$$\omega_i(t) = \omega_i^r(t) + \omega_i^\ell(t). \qquad (1)$$

We first define `per-location load` and `network-wide load` and then design the proposed framework of provisioning service differentiation based on `per-location target load`.

**Per-location load:** The portion of link capacity allotted for each location is initially given to the AP according to per-location weight. Therefore, per-location load $\omega_i^r$ should not exceed the preassigned per-location link capacity. Also, since the load is dynamically changed due to the number of locations $N$, we need to trace the current load for each location and give positive (negative) incentive to a specific location that has exploited wireless link capacity less (more) than its given link per-location capacity.

In order to identify the course of per-location load `TaLE` is positioned at the link layer and entitled to keep track of load for each location. Let $C_i$ denote per-

location share of link capacity during a given wireless link monitoring interval, $T_{\omega^r}$. If the link is shared by $N$ locations, then we compute

$$C_i = \left( \frac{\phi_i}{\sum_{k=1}^{N} \phi_k} \right) \times C,$$

where $\varphi_i$ represents the positive weight of the $i$th location, and $C$ is the maximally achievable link capacity. This equation implicitly includes the proportional fairness among traffics, and thus if one of them uses less amount of capacity than its allotted capacity $\varphi_i$, the other traffics can additionally share the surplus bandwidth.

During every interval, $T_{\omega^r}$, of monitoring the link, the TaLE estimates the amount of traffic $a_i$ for the $i$th location. Whenever the AP sends/receives a data frame for any station at the $i$th location TaLE increases $a_i$ by the amount of $L = t_{oh} \times C$, where $L$ denotes the frame size and *toh* denotes the time to process overhead involved to the frame transmission, such as inter-frame space time, back off time, ACK transmission time, and RTS/CTS handshake time if it is used.

With per-location link access amount $a_i$ (bits) and per-location link capacity $C_i$ (b/s) TaLE calculates the current per-location load $\omega_i^r$ as follows: Since $a_i[k]$ and $C_i$ denote the amount of link usage and per-location link capacity of the $i$th location at the $k$th monitoring interval, i.e., $t = k \cdot T_{\omega^r}$, per-location (aggregate) rate $r_i[k]$ is

$$r_i[k] = \frac{a_i[k]}{T_{\omega^r}},$$

and $\omega_i^r[k]$ is calculated as

$$\omega_i^r[k] = \begin{cases} \mathcal{K} \cdot \left( 1 - \frac{C_i}{r_i[k-1]} \right) & \text{if } a_i[k-1] > 0 \\ \mathcal{K} & \text{otherwise}, \end{cases} \quad (2)$$

where $\mathcal{K}$, $0 < \mathcal{K} \leq 1$ is a scaling parameter. Note that this rate-based per-location load can be expressed in either amount-based or time-based per-location load since the amount allocated to the $i$th location is $C_i \times T_{\omega^r}$ and the per-location access time of the $i$th location is $\left( \phi_i / \sum_{k=1}^{N} \phi_k \right) \times T_{\omega^r}$.

Conclusively, if all the stations at the $i$th location $R_i$ have imposed load on the link excessively more than given per-location portion of wireless link capacity in the previous monitoring interval, i.e., $r_i[k-1] > C_i$, then TaLE delivers to traffic senders per-location load increased by $\omega_i^r[k]$ at the current interval. If $r_i[k-1] < C_i$ TaLE feedback decreased per-location load to compensate any station at the $i$th location for the less

usage of per-location link capacity in the previous interval.

**Network-wide load:** Even though per-location load at the $i$th location is used to adjust the rate of traffic senders to a desirable level, the traffic directed from/to the location contributes to the aggregate traffic perceived at the AP, so that it may congest the AP and consequently influence on other traffic (which belongs to other locations). In order to reduce excessive contribution of per-location traffic to the network-wide load TaLE also estimates the network-wide load, $\omega_i^\ell$, and includes it in the computation of per-location target load.

The network-wide load is tightly related to packet losses incurred due to the aggregate input rate larger than the current link capacity. Let us define the *current network-wide load* $\ell(t)$ at a time instant of $t$ as the difference between the aggregate input rate $r(t)$ and wireless link capacity $C(t)$, which in turn represents the change rate of the current queue length:

$$\ell(t) = r(t) - C(t) = \frac{\mathrm{d}}{\mathrm{d}t} q(t). \quad (3)$$

Let $\ell[k]$ and $\ell_{\mathrm{ref}}[k]$ denote the *current network-wide load* and its *target load*, respectively, at the $k$th monitoring time instant, i.e., at the time instant of $k = t/T_{\omega^\ell}$, where $T_{\omega^\ell}$ is a given interval of monitoring the network-wide traffic. Here, the *target load* means *tolerable traffic* which can be remained at the AP and cleared out before newly arrived traffic is processed without incurring unnecessary droppings. Based on $\ell[k]$ and $\ell_{\mathrm{ref}}[k]$, the network-wide load $\omega_i^\ell[k]$ at the time instant $k$ is determined as:

$$\omega_i^\ell[k] = \alpha(\ell[k] - \ell_{\mathrm{ref}}[k]), \quad (4)$$

where $\alpha(>0)$ is a control gain. This equation quantifies the difference by which the *current network-wide load* becomes more (or less) than its *target load*.

In order to compute the deviation of the *current network-wide load* from its *target load* in (4), we first determine the *current network-wide load* $\ell[k]$ based on (3) as follows:

$$\ell[k] = r[k] - C[k]. \quad (5)$$

Then, in order to determine the *target load* $\ell_{\mathrm{ref}}$, we introduce a *tolerable queue length* at the AP, $q_{\mathrm{ref}}$, for the purpose of accommodating the aforementioned *tolerable traffic*, i.e., a small mismatch between the link capacity and the imposed traffic, and finally determine the target load $\ell_{\mathrm{ref}}$ as:

$$\ell_{\mathrm{ref}}[k] = \beta \left( \frac{q_{\mathrm{ref}} - q[k]}{T_{\omega^\ell}} \right) - \Delta \ell_{\mathrm{ref}}[k], \quad (6)$$

where $\beta(>0)$ is a control gain, $q[k]$ is the AP queue length, and $\Delta\ell_{\rm ref}[k]$ denotes an accumulated deviation from the *target load*. The $\Delta\ell_{\rm ref}[k]$ in (6) can be recursively defined as:

$$\Delta\ell_{\rm ref}[k] = \Delta\ell_{\rm ref}[k-1] + \gamma\left((r[k] - C[k]) + \beta\left(\frac{q_{\rm ref} - q[k]}{T_{\omega^\ell}}\right)\right), \quad (7)$$

where $\gamma(>0)$ is another gain.

From (6) and (7), the difference between $\ell[k]$ and $\ell_{\rm ref}[k]$ in (4) is determined as:

$$\ell[k] - \ell_{\rm ref}[k] = (r[k] - C[k]) - \beta\left(\frac{q_{\rm ref} - q[k]}{T_{\omega^\ell}}\right) + \gamma\sum_{j=0}^{k}\left((r[j] - C[j]) - \beta\left(\frac{q_{\rm ref} - q[j]}{T_{\omega^\ell}}\right)\right). \quad (8)$$

Additionally, we remove the term of $(r[j] - C[j])$ with the following approximation based on (3):

$$r[j] - C[j] = \left(\frac{q[j] - q[j-1]}{T_{\omega^\ell}}\right). \quad (9)$$

Based on (4)-(9), the `TaLE` algorithm can easily calibrate the network-wide load with only the queue length, without estimating the aggregate input rate, or the current wireless link capacity and thus the network-wide load is as:

$$\omega_i^\ell[k] = \alpha\left[\left(\frac{1}{T_{\omega^\ell}} + \frac{\beta}{T_{\omega^\ell}} + \frac{\gamma}{T_{\omega^\ell}}\right)q[k] - \frac{1}{T_{\omega^\ell}}q[k-1] - \frac{\beta}{T_{\omega^\ell}}q_{\rm ref} - \frac{\beta\gamma}{T_{\omega^\ell}}\sum_{j=0}^{n}\left(q_{\rm ref} - q[j]\right)\right]. \quad (10)$$

`TaLE`-**based Framework of Service Differentiation:**
With current per-location load of the $i$th location $R_i$ and its contribution to network-wide load, we can devise a total `TaLE` framework to provide *location-based* service differentiation and fairness in IEEE 802.11-based Hot Spot networks. The details on how to use and estimate `per-location target load` in `TaLE` will be accounted for in what follows, and also the overall

`TaLE` framework is demonstrated in Figure 3.

• At every given interval `TaLE` sets per-location target load by estimating the current per-location load and its contribution to current network-wide load, based on current link usage, aggregate input rate, and wireless link capacity;
• Once a packet (TCP data or ACK packet) arrives to the AP, the `TaLE` identifies the location to which the packet belongs, then randomly chooses a number between zero and one, and compares it with the previously computed target load value: if the number is less than the load, it marks a single bit of `TaLE` (for which we use one bit from the undefined subtype of frame control field) in the MAC header; thus, the information is piggybacked on the data frame from the AP to its sending station;
• On receiving a packet whose `TaLE` bit is set, the station should deliver the information to the transport layer. If the IP layer sees `TaLE` bit (in MAC header) set, it marks the ECN bit [38] in the IP header. If the station is a receiver, the `TaLE` bit is returned to the corresponding sender via its corresponding TCP ACK packet. It needs to be noticed that since the ECN bit plays the role of delivering the result of `TaLE` framework to the sending station and does not affect the performance, any other feedback scheme can be used with the `TaLE` framework;
• Finally, the TCP sender recognizes its current contribution to per-location load through the ECN bit and then accordingly adjusts its congestion window by halving the window.

As for the computational complexity of the proposed `TaLE` framework, we have the following investigation
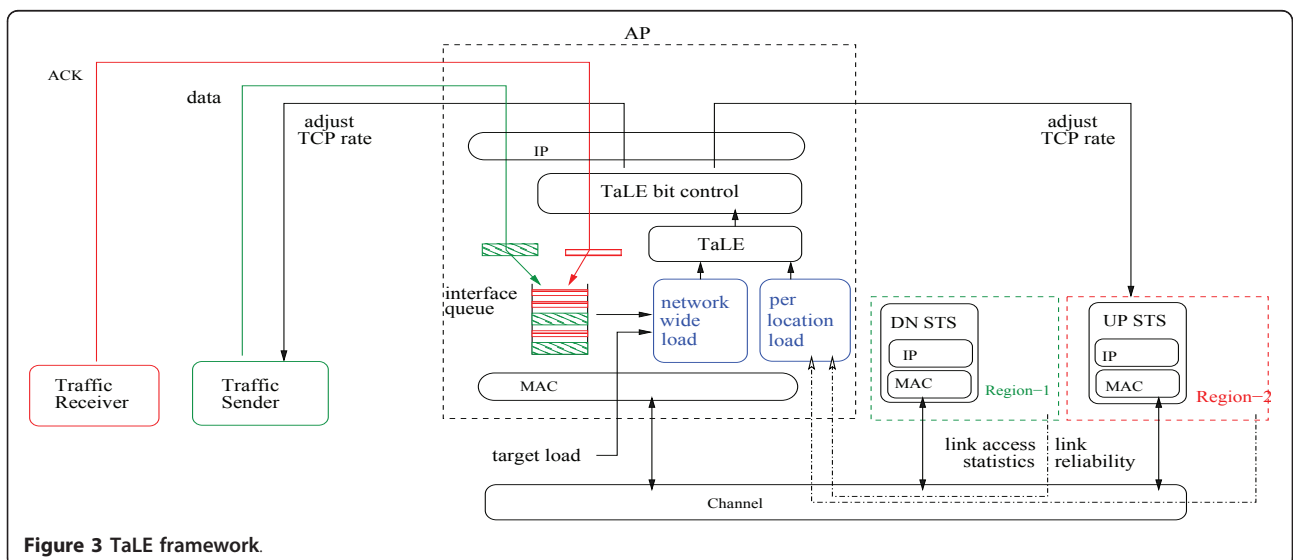


**Figure 3 TaLE framework**.

results. As aforementioned, the AP equipped with `TaLE` framework needs to compute the `per-location target load` by estimating the current per-location load and its contribution to the current network-wide load with link reliability, aggregate input rate, and network-wide load every $T_{\omega^\ell}$ interval time. And, the AP decides whether or not it marks each packet with the computed target load. Since the computation involves to only several additions and multiplications, the computation is not computation demanding (that requires high-end computing powers). Additionally, the AP does not need to keep track of per-connection (per-flow) statistics, but instead, it keeps track of per-location statistics, and the tracked statistics are simply the amount of successfully transmitted packets. Therefore, the overhead is surely acceptable in both keeping track of per-location statistics and computing `per-location target load`.

Note that the proposed `TaLE` framework can be incorporated with any transport protocol with a feedback control scheme, but, since it is out of scope to introduce or devise such the protocol, we simply use TCP protocol to completely construct it.
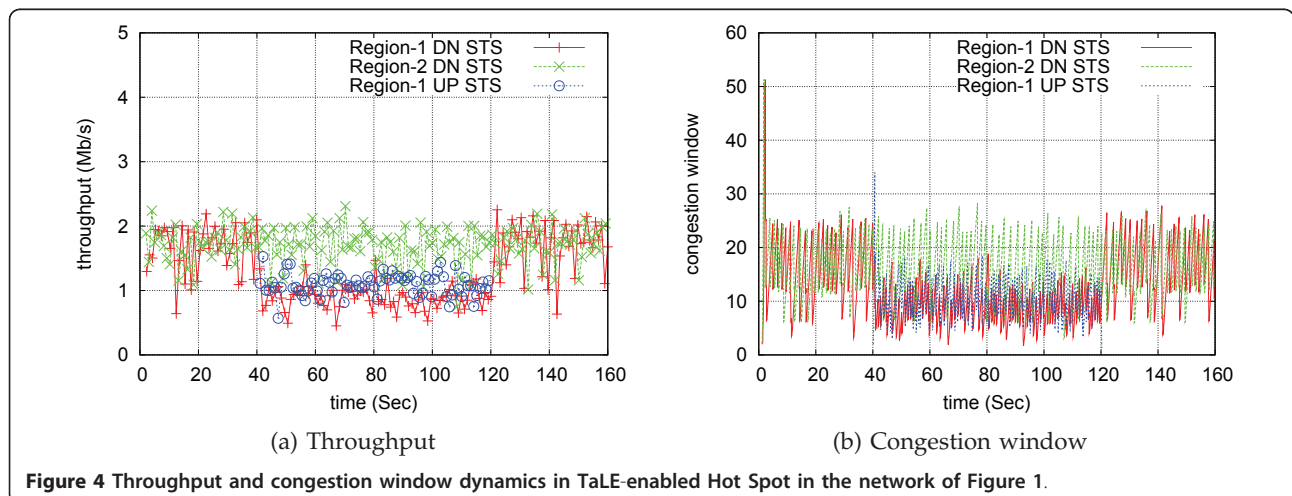
## 5 Validation

We firstly validated that the `TaLE` framework solves both problems of unfairness and service differentiation that we dealt with at Section 1 with Figures 1-2.

### 5.1 Location-based fairness

With the same network configuration and scenario used in Figures 1-2 at Section 1, we first verified the effect of `TaLE` framework on per-location fairness. Note that each location has the same weight in this simulation to evaluate fairness. In this simulation, we do not enable the RTS/CTS mechanism and we have little concern

about hidden terminals since we assume all the stations hear each other. The allocated buffer size, $B$, for all queues is set to 100 packets, and the maximum congestion window size of TCP is set to 50 packets. We employ TCP/Reno and set TCP packet size to 1500 bytes. The parameters of the `TaLE` framework, $\alpha$, $\beta$, $\gamma$, and $\mathcal{K}$, are set to 0.0003, 0.03, 0.05, and 0.8, respectively, to minimize queue length error according to the tuning technique specified in [39], and the interval of monitoring per-location load $T_{\omega^r}$, and that of updating network-wide load $T_{\omega^\ell}$ are set to 10 and 10 ms, individually. These settings are continuously used for the subsequent simulation study in Section 6.

Figure 4a presents per-station throughput dynamics according to the given scenario. Specifically, we make the following observations: (*i*) In the period of [0s, 40s], the `TaLE` framework allocates 1.65 and 1.73 Mb/s to `Region-1` (DN STS) and `Region-2` (DN STS), respectively, which is more fair bandwidth allocation between two regions, compared to the case without `TaLE` (see Figure 2); (*ii*) When `Region-1` comes to have UP STS during the period of [40s, 120s] `TaLE` distributes 0.89 and 1.09 Mb/s to DN STS and UP STS at `Region-1`, respectively, which are in total 1.98 Mb/s, but it allocates 1.68 Mb/s to DN STS at `Region-2`, which is decreased from the previous period of [0s, 40s]; (*iii*) In the last period of [120s, 160s], the throughput of DN STS at `Region-1` is 1.70 Mb/s while that in `Region-2` is 1.72 Mb/s. As already noticed, the `TaLE` framework enforces bandwidth allocation to be compliant with given weights and the allocation is conducted for each identified location, not for each station. Note that in the period of [40s, 120s], the aggregate throughput at `Region-1` (i.e., 1.98 Mb/s) is almost equal to that at `Region-2` (i.e., 1.68 Mb/s) and also that the throughput of `Region-2` is not much affected by the time-



**Figure 4 Throughput and congestion window dynamics in TaLE-enabled Hot Spot in the network of Figure 1.**

varying number of stations at `Region-1`. Figure 4b presents the congestion window dynamics observed in all the stations in the network. We can easily observe the similar trend to the per-station throughput observed in Figure 4a.

## 5.2 Location-based service differentiation

In order to verify that the `TaLE` framework achieves more elaborate service differentiation, we carry out an additional simulation study. In this study, we use a simplified network configuration in that each region has one station in the network of Figure 1, but employs the following complex simulation scenario:

- `Region-1` has `DN STS` active throughout the whole period of [0s, 160s];
- `Region-2` has `UP STS` during the period of [20s, 140s];
- Both `Region-1` and `Region-2` have the same weight of 1 initially;
- `Region-1` comes to have the weight of 4 in the interval of [40s, 80s], and the weight returns to 1 after this interval;
- `Region-2` starts to have the weight of 4 in the interval of [80s, 120s], and it returns to 1 at the instant of 120s.

Note that the higher number means the higher weight (priority).

From Figure 5a, we can observe that the `TaLE` framework enforces fairness among two regions when their priorities are equal, regardless of uploading or downloading station, shown in periods of [20s, 40s] and [120s, 140s]; in specific, `Region-1` (`DN STS`) achieves 1.73 (1.69 Mb/s) in the period of [20s, 40s] ([120s, 140s]) while `Region-2` (`UP STS`) uses 1.72 (1.75 Mb/s)

in the corresponding period. Also, we can see that it gives service differentiation between two regions according to the weight given to each region. In the period of [40s, 80s], `Region-2` serves `UP STS` with 2.85 Mb/s while `Region-1` does `DN STS` with 0.75 Mb/s, but when we exchange weights between `Region-1` and `Region-2`, the ratio of throughput in `Region-1` and 2 becomes reversed; in specific, `DN STS` at `Region-1` exploits 2.55 Mb/s but `UP STS` at `Region-2` uses 0.85 Mb/s. Figure 5b presents congestion windows observed in `DN STS` at `Region-1` and `UP STS` at `Region-2`. We can observe the same trend of dynamics as done in TCP throughput according to weights assigned to each region. These results are presented in Table 1. Conclusively, the `TaLE` framework supports per-location service differentiation and fairness efficiently.

## 6 Performance evaluation

In this section, we conduct a *ns-2* simulation study with more various perspectives so as to demonstrate the properties of the `TaLE` framework. The network topology we use is presented in Figure 6. The AP coverage (100 m × 100 m) is divided into three regions that are `Region-1`, `Region-2`, and `Region-3`. These regions are not overlapped each other. Stations positioned at each region, `STS-1`, `STS-2`, and `STS-3` communicate with their corresponding wired stations two hops away from them. Link capacity and delay for wired stations are also presented in the figure.

Simulation study has been carried out in three phases (*i*) single-station case where each region has one station with one flow, (*ii*) multi-station case where each region has two or more number of stations, and (*iii*) heterogeneous station case where each region serves one station with a different number and type of flows. With these three phases of evaluation, we verify whether the `TaLE`
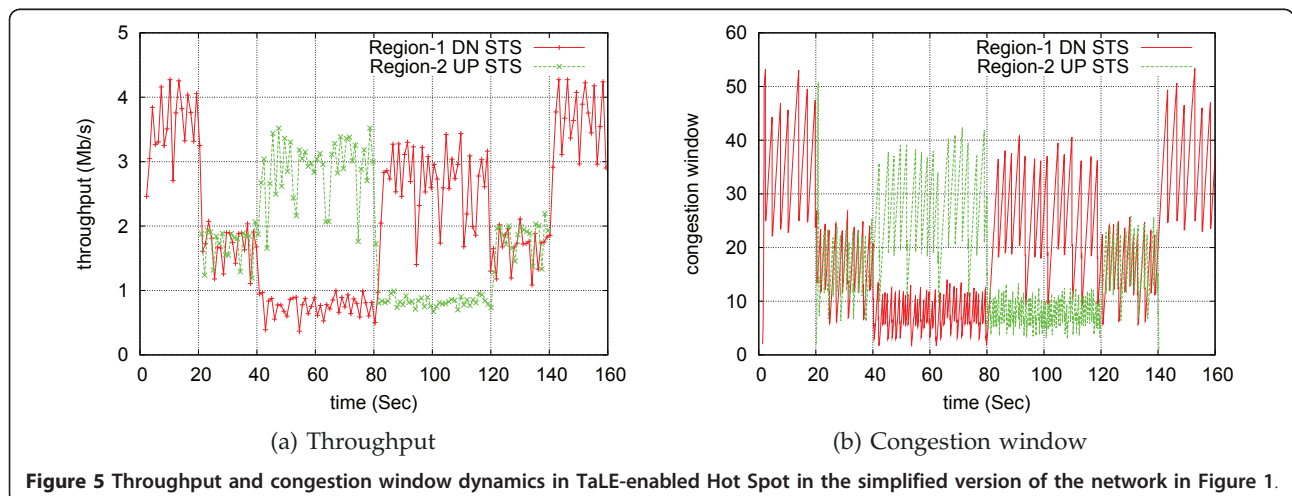


**Figure 5 Throughput and congestion window dynamics in TaLE-enabled Hot Spot in the simplified version of the network in Figure 1.**

**Table 1 Average per-location throughput in `TaLE`-enabled Hot Spot**

| Time interval | Region-1 | Region-2 |
|---|---|---|
| [0s, 40s] | 3.54 | - |
| [20s, 40s] | 1.73 | 1.72 |
| [40s, 80s] | 0.75 | 2.85 |
| [80s, 120s] | 2.55 | 0.85 |
| [120s, 140s] | 1.60 | 1.75 |
| [140s, 160s] | 3.64 | - |

framework can support service differentiation among regions, irrespective of wireless errors, mobility, the number of stations per location, or the number of flows per station.

### 6.1 Performance in case of single-station
We first conduct a simulation study where each station in Figure 6 has only one flow: two stations `STS-1` and `STS-2` download data from the corresponding wired station while one station `STS-3` uploads its data to its wired peer. Note that we have similar results (stated below) for the cases of other combinations with upload and download, even though we do not present them due to the space limit.

#### 6.1.1 Performance with respect to per-location throughput
As the first simulation study, we investigate the fairness and service differentiation among regions, with the following simulation scenario:

- `Region-1` has `STS-1` active throughout the whole period of [0s, 180s];
- `Region-2` starts to serve the `STS-2` at the instant of 20s, and stops it at 140s;

- `Region-3` accommodates `STS-3` during the interval of [40s, 160s];
- `Region-1`, `Region-2`, and `Region-3` are initially assigned to the same weight of 1;
- `Region-1`, `Region-2`, and `Region-3` are assigned to highest weight (3), the middle one (2), and the lowest weight (1), individually, during the interval of [60s,120s];
- All the stations do not move around in the network;
- Ten simulation runs are carried out for each network simulation, but we choose one when we present the throughput dynamics.

Figure 7 presents TCP throughput dynamics of IEEE 802.11-based Hot Spot and that of `TaLE`-enabled Hot Spot. As for IEEE 802.11-based Hot Spot network in Figure 7a, we can observe no considerable discrepancy between two regions (`Region-1` and `Region-2`) in the period of [20s, 40s] when no station at `Region-3` appears yet. When `STS-3` starts to upload data at the instant of 40s, it dominates to use network bandwidth in the period of [40s, 140s]. The throughput of `Region-1` and `Region-2` is significantly degraded in this period.

On the contrary, `TaLE`-enabled Hot Spot does not suffer from such the unfairness. Figure 7b presents that all the regions successfully achieve both the per-location fairness and service differentiation at each period. In the period of [20s, 40s], the average throughput of `Region-1` and that of `Region-2` are almost equal to each other (2.14 and 1.94 Mb/s, respectively). Similarly, in the period of [40s, 60s], all the three regions share the bandwidth evenly. When different weights are
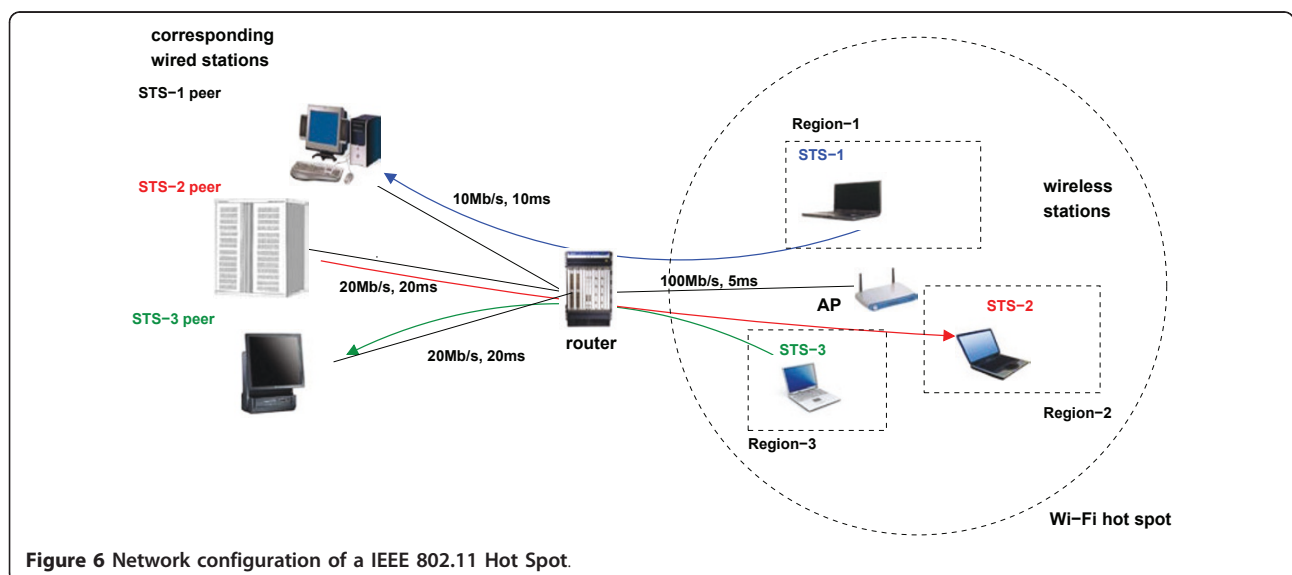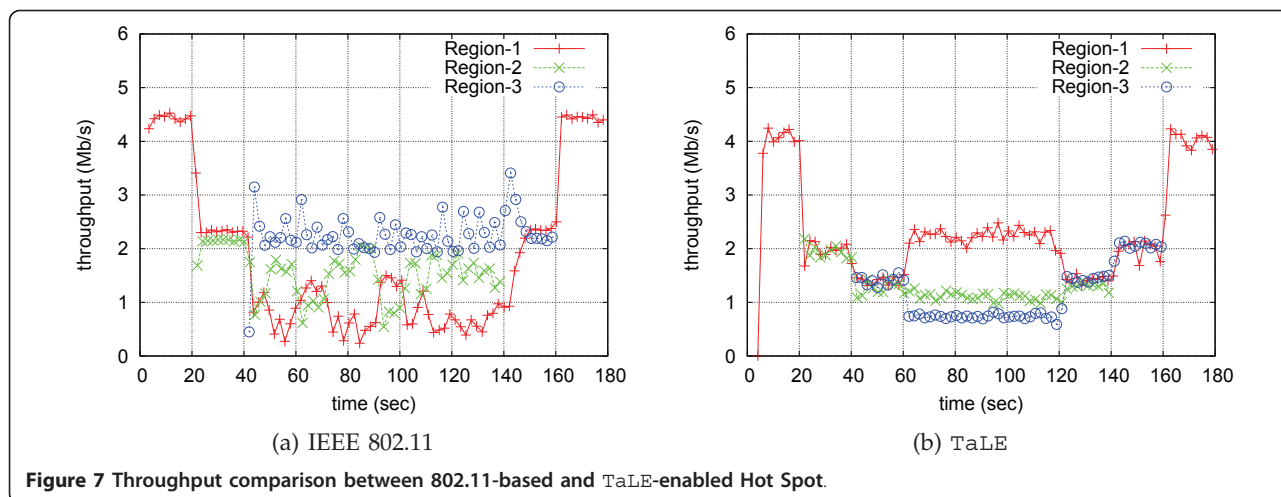


**Figure 6 Network configuration of a IEEE 802.11 Hot Spot**.

**Figure 7 Throughput comparison between 802.11-based and TaLE-enabled Hot Spot.**

assigned to each Region in the period of [60s, 120s], each region exploits different amount of network bandwidth according to its assigned weight. After STS-2 leaves the network at the instant of 140s, the remaining STS-1 and STS-3 equally share the available bandwidth (in the period of [140s, 160s]). Consequently, perlocation throughput in the period of [20s, 40s], [40s, 60s], [120s, 140s], and [140s,160s] is nearly equal to one another. In specific, numerical comparison between perlocation throughput of IEEE 802.11-based Hot Spot and that of TaLE-enabled Hot Spot is presented in Table 2. As already discussed with Figure 7, we continuously observe that TaLE framework can accurately support service differentiation and/or fairness according to a given set of per-location weights. In order to quantitatively evaluate the fairness among regions when all the regions are assigned to the same weight, we use the following *Jain's index* [40]:

$$\mathcal{F} = \left( \sum_{i=1}^{N} \mu_i \right)^2 / \left( N \sum_{i=1}^{N} \mu_i^2 \right), \qquad (11)$$

**Table 2 Comparison of average per-location throughput between IEEE 802**

| Time interval | IEEE 802.11-based Hot Spot | | | TaLE-enabled Hot Spot | | |
|---|---|---|---|---|---|---|
| | Region-1 | Region-2 | Region-3 | Region-1 | Region-2 | Region-3 |
| [0s, 20s] | 4.42 | - | - | 4.06 | - | - |
| [20s, 40s] | 2.43 | 2.10 | - | 2.14 | 1.94 | - |
| [40s, 60s] | 0.89 | 1.48 | 2.15 | 1.43 | 1.30 | 1.41 |
| [60s, 120s] | 0.87 | 1.39 | 2.19 | 2.21 | 1.11 | 0.76 |
| [120s, 140s] | 0.67 | 1.57 | 2.29 | 1.47 | 1.26 | 1.38 |
| [140s, 160s] | 1.98 | - | 2.48 | 2.00 | - | 2.04 |
| [160s, 180s] | 4.24 | - | - | 3.89 | - | - |

where $N$ is the number of regions (stations) and $\mu_i$ is the throughput of the $i$th region. The $\mathcal{F}$ has the maximum value of when each region has the same throughput. Table 3 presents such the fairness index at the periods of [20s, 40s], [40s, 60s], [120s, 140s], and [140s, 160s]. We easily confirm that the TaLE framework can accurately provide the fairness among regions when all the regions have the same weight, in addition to service differentiation in the other case.

### 6.1.2 Performance in the presence of link errors

In order to handle wireless link errors within TaLE framework, we need to measure and reflect link reliability into the proposed algorithm. Underlying reasoning for this information is that the aggregate input rate of $i$th location $R_i$ should be compliant with per-location portion of link capacity even when wireless link errors degrade wireless link capacity. But, this is another research, which is out of scope of this paper, and the interested readers are referred to [41-44]. As an *interim solution*, we propose a simple beaconing scheme in which every station is supposed to broadcast a beacon frame at every period of $T_{beacon}$. The AP keeps tack of the number of successfully received beacon frames from each station. We then employ the ratio of the number of successfully received frames to the total number of transmitted frames as the link reliability. Henceforth, per-location load $\omega_i^r$ in (2) is changed to what follows:

**Table 3 Comparison of fairness index between IEEE 802**

| Time interval | IEEE 802.11-based Hot Spot | TaLE-enabled Hot Spot |
|---|---|---|
| [20s, 40s] | 0.995 | 0.999 |
| [40s, 60s] | 0.896 | 1.000 |
| [120s, 140s] | 0.840 | 0.998 |
| [140s, 160s] | 0.987 | 1.000 |

$$\omega_i^r[k] = \begin{cases} \mathcal{K} \cdot \left\{ \left(1 - \frac{C_i}{r_i[k-1]}\right) \times \omega_i^s \right\} & \text{if } a_i[k-1] > 0 \\ -\mathcal{K} & \text{otherwise,} \end{cases} \quad (12)$$

where $\omega_i^s (0 < W_i^s \leq 1)$ is the per-location link reliability based on aforementioned beaconing scheme for the location $R_i$. The specific algorithm of determining $\omega_i^s$ is in what follows. Let $\delta_{R_i}[k]$ denote the successful transmission rate of the $i$th location during a given interval. Then, the link reliability for the $i$th location, $\omega_i^s[k]$, is given as

$$\omega_i^s[k] = \delta_{R_i}[k-1]. \quad (13)$$

If it receives $n_i^b$ beacon frames from station $i$ among last $1/T_{\text{beacon}}$ number of beacons, $\delta_{R_i}$ is $\frac{n_i^b}{1/T_{\text{beacon}}}$. Note that $T_{\text{beacon}}$ is independent of $T_{\omega^r}$ and TaLE considers last $1/T_{\text{beacon}}$ number of beacons in calculating $\omega_i^s$. Therefore, if a certain location experiences transmission failure frequently, then its reliability becomes lower and lower, reducing per-location load $\omega_i^r$. *Note that the above beaconing-based scheme for estimating link reliability can be replaced with any scheme of estimating the link reliability.*

Based on this new modified per-location load $\omega_i^r$, we carry out a simulation study when a wireless link error scenario comes into play in order to see whether the fairness is supported in time-varying unreliable wireless link, which is to verify the role of $\omega_i^s$ in calculating per-location load, $\omega_i^r$, in (2). We set $T_{\text{beacon}}$ to 50 ms for this simulation study. We basically use the same simulation scenario as used in Section 6.1.1 except

- all the regions have the same weight in the whole period,

and we employ two-state semi-Markov-modulated process in order to generate wireless link errors as follows:

- in OFF state, the wireless link is error-free, while frame error occurs in ON state with the average probability of 0.9;
- the periods of OFF and ON states are sustained during 100 and 75 ms, respectively;
- the state transition probability matrix is given as

$$\begin{pmatrix} P_{\text{off-off}} & P_{\text{off-on}} \\ P_{\text{on-off}} & P_{\text{on-on}} \end{pmatrix} = \begin{pmatrix} 0.2 & 0.8 \\ 0.6 & 0.4 \end{pmatrix}, \quad (14)$$

- only Region-1 suffers from the link errors in the period of [60s, 120s].

Figure 8 and Table 4 present throughput dynamics of TaLE-enabled Hot Spot and its fairness index at each period in comparison with IEEE 802.11-based network in part. Note that we do not present throughput dynamics of EEE 802.11-based network since they are similar to those presented in Section 6.1.1 and easily inferred from fairness indices. In specific, Figure 8 exhibits that the TaLE framework can address wireless link errors and still support per-location fairness even though wireless errors disrupt transmissions in Region-1. We can conclusively acknowledge that, even if wireless link errors are incurred in Region-1, the service differentiation supported by the TaLE framework continuously works with small throughput degradation at all the regions while exiting IEEE 802.11-based network does not respond to the errors. In case of fairness index presented in Table 4 (b), we clearly see that when all the regions have the same weight, i.e., [20s, 40s], [40s, 60s], [60s, 120s], and [120s, 140s], the TaLE framework allocates the link capacity to each region almost equally even though wireless link errors reduce the capacity and consequently degrade the index somewhat (see the index when errors appear, i.e., the period of [60s, 120s]). In fact, $\omega_i^s$ portion of per-location load information compensates unsuccessful transmissions due to wireless link errors by lowering per-location target load.

### 6.1.3 Performance in the presence of mobility

As the next performance study, we investigate the effect of station mobility on the TaLE framework. We use the following mobile scenario, in addition to the scenario used in Section 6.1.1:

- STS-1 moves to Region-3 from Region-1 while STS-3 moves to Region-1 from Region-3 at the instant of 80s at the speed of 1 m/s.
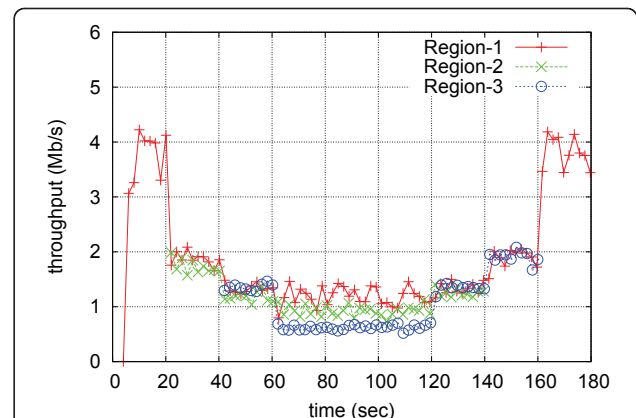


**Figure 8 Throughput dynamics of TaLE-enabled Hot Spot in the presence of wireless link errors.**

**Table 4 Fairness index of `TaLE`-enabled Hot Spot in the presence of wireless link errors**

| Time interval | IEEE 802.11-based Hot Spot | TaLE-enabled Hot Spot |
|---|---|---|
| [20s, 40s] | 0.998 | 0.993 |
| [40s, 60s] | 0.902 | 1.000 |
| [60s, 120s] | 0.713 | 0.950 |
| [120s, 140s] | 0.836 | 1.000 |
| [140s, 160s] | 1.000 | 1.000 |

Figure 9 and Table 5 present per-station throughput in `TaLE`-enabled network in comparison with those in IEEE 802.11-based Hot Spot network. Note that we present in this figure per-station throughput dynamics instead of per-location throughput since stations `STS-1` and `STS-3` exchanges their positions. In Figure 9, we can perceive that the `TaLE` framework provides distinct service differentiation agreeable to given weights. Especially, in the period of [60s, 80s], `STS-1` station enjoys the highest bandwidth among three stations since `Region-1` has the highest weight, but, after `STS-1` and `STS-3` stations exchange their positions according to the mobile scenario, `STS-3` is entitled to use the highest bandwidth since its current location becomes `Region-1` with the highest weight. Once all the regions come to have the same weight, i.e., the periods of [40s, 60s], and [120s, 140s], we can see all the stations use equal quantity of network bandwidth. Table 5 compares numerically per-station throughput between IEEE 802.11-based and `TaLE`-enabled Hot Spot network at each period.

## 6.2 Performance in case of multiple stations

In this section, we do a simulation investigation when each region has multiple stations to evaluate the `TaLE` framework in perspective of per-location throughput,



**Figure 9 Throughput in TaLE-enabled Hot Spot in the presence of mobility**.
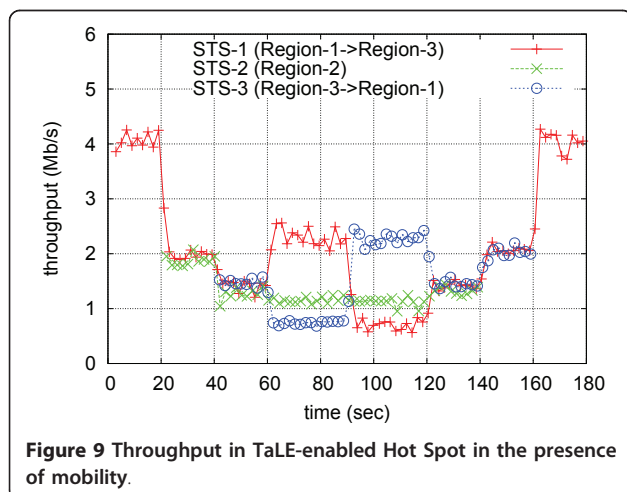
network-wide throughput, and loss rate when the number of stations per location increases.

### 6.2.1 Performance with respect to per-location throughput

In the extended line of previous simulation studies in Section 6.1, we evaluate the `TaLE` framework with respect to per-location throughput when multiple stations appear at each region. The simulation scenario is as follows:

- `Region-1` and `Region-2` have two downloading station while `Region-3` has two uploading station;
- all the regions serve their resident stations during the whole simulation period of 100s;
- `Region-1`, `Region-2`, and `Region-3` have 1, 2, and 3 as its weight, respectively.
- all the regions suffer from wireless link errors, which are generated by the same way as used in Section 6.1.2, except:
  - the errors appear in the period of [30s, 70s].

Figure 10 and Table 6 show that `TaLE`-enabled network supports per-location service differentiation immune to wireless link errors (Figure 10) and presents per-location aggregate throughput in each interval (Table 6). Since weights given to `Region-1`, `Region-2`, and `Region-3` are 1, 2, and 3, respectively, we can simply check whether or not the `TaLE` framework works by comparing the summed throughput of `Region-1` and `Region-2` with throughput of `Region-3`. As shown in the Table as well as the figure, we confirm that the `TaLE` framework can accurately support location-based service differentiation according to given weights, regardless of wireless link errors and the number of stations per location.

### 6.2.2 Performance in the presence of mobility

Then, we investigate whether the `TaLE` framework can be immune to the mobility. We continuously use the same simulation configuration that we have used for the Section 6.2.1, and we have additional scenarios as follows:

- `STS-2` moves to `Region-3` from `Region-1`, `STS-4` moves to `Region-1` from `Region-2`, and `STS-6` moves to `Region-2` from `Region-3` at the instant of 40s at the speed of 10 m/s;
- Wireless link errors are disabled.

The results are shown in Figure 11a. We can observe from the figure that even though mobile nodes appear in the network, the location-based differentiation is successfully supported by the `TaLE` framework.

In addition, we enable the wireless link in the above simulation scenario in order to see how both wireless link errors and mobility affect the `TaLE` framework.

**Table 5 Average per-location throughput in `TaLE`-enabled Hot Spot in the presence of mobility**

| Time interval | STS-1 (Region-1 → Region-3) | STS-2 | STS-3 (Region-1 → Region-3) |
|---|---|---|---|
| [0s, 20s] | 4.06 | - | - |
| [20s, 40s] | 2.06 | 1.88 | - |
| [40s, 60s] | 1.45 | 1.32 | 1.46 |
| [60s, 80s] | 2.31 | 1.15 | 0.73 |
| [80s, 120s] | 1.13 | 1.14 | 1.85 |
| [120s, 140s] | 1.39 | 1.32 | 1.52 |
| [140s, 160s] | 2.05 | - | 2.00 |
| [160s, 180s] | 3.89 | - | - |

The scenario for generating wireless link errors is the same one as used in the Section 6.2.1; in other words, wireless link errors appear in the period of [30s,70s]. Figure 11b presents the results that shows the `TaLE` framework works well in the combined presence of wireless link errors and mobile nodes.

### 6.2.3 Performance with respect to aggregate throughput and loss rate

Based on the results in Section 6.2.1, we further investigate whether the `TaLE` framework still holds its effect when each region includes varying number of stations. We continuously use the same simulation scenario as employed in Section 6.2.1, but we have the following modifications on the scenario:

- each simulation set uses a different number of stations per region, varying from one to five;
- each simulation set has 10 number of runs, each of which is executed with a different seed;
- all the regions are free from wireless link errors.

Notice that since each set includes 10 runs, all the results are presented in average.
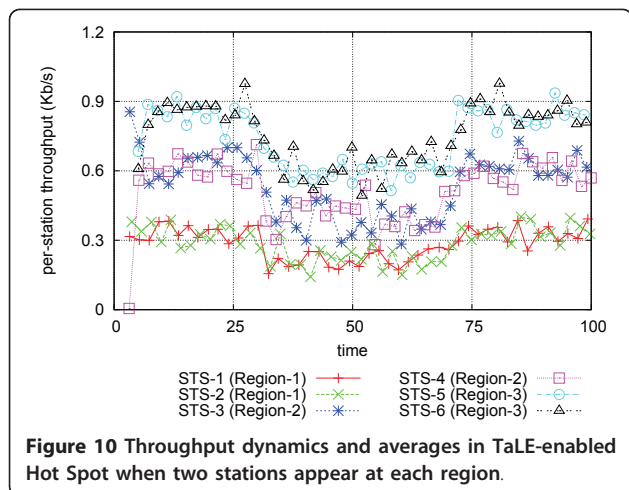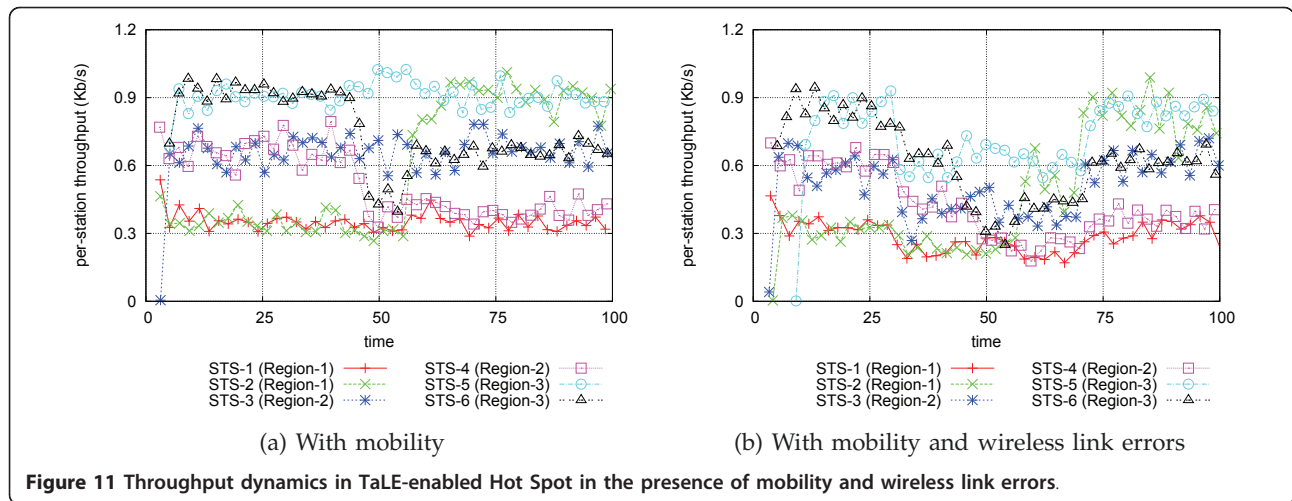


**Figure 10 Throughput dynamics and averages in TaLE-enabled Hot Spot when two stations appear at each region**.

Firstly, we evaluate the `TaLE` framework with respect to per-location throughput. Figure 12 presents aggregate per-location throughput as the number of stations per region increases. The aggregate throughput means total throughput cross all the stations in the region. As indicated in Figure 12, IEEE 802.11-based network cannot manage to do anything when the region `Region-3` (which has only uploading stations) dominates to exploit link capacity. The unfairness results from the inter-play between TCP and IEEE 802.11 MAC protocols [35,36,45]. The aggregate throughput of `Region-3` increases from 2.09 (through 3,26, 3.95, and 4.18) up to 4.11 Mb/s when the number of nodes increases from 1 to 5, while `Region-1` (`Region-2`) decreases from 0.98 (1.40) to 0.10 (0.16) Mb/s. Note that the discrepancy between `Region-1` and `Region-2` comes from different round trip time due to different link capacity and delay between router and their corresponding wired peer. On the contrary, the `TaLE` framework prevents any region from excessively exploiting link capacity, which is presented in Figure 12(b). `Region-1` uses 1.30 ~ 1.39 Mb/s, `Region-2` uses 1.30 ~ 1.42 Mb/s, and `Region-3` uses 1.42 ~ 1.56 Mb/s, regardless of the number of stations per region.

Then, we evaluate the `TaLE` framework in perspective of the network-wide aggregate throughput and frame loss rate. Figure 13 compares the network-wide aggregate throughput and loss rate between IEEE 802.11-based and the `TaLE` framework. From the figure, we first observe that, even though the network-wide throughput is stable, immune to the number of stations

**Table 6 Average per-location throughput in `TaLE`-enabled Hot Spot when two stations appear at each region**

| Time interval | Per-station/region throughput (Mb/s) | | |
|---|---|---|---|
| | Region-1 | Region-2 | Region-3 |
| [0s, 30s] | 0.34 +0.34 = 0.68 | 0.62+0.54 = 1.16 | 0.92+0.94 = 1.86 |
| [30s, 60s] | 0.21 +0.22 = 0.43 | 0.37+0.39 = 0.76 | 0.67+0.68 = 1.35 |
| [60s, 100s] | 0.31 +0.30 = 0.60 | 0.52+0.52 = 1.04 | 0.86+0.88 = 1.74 |

(a) With mobility

(b) With mobility and wireless link errors

**Figure 11 Throughput dynamics in TaLE-enabled Hot Spot in the presence of mobility and wireless link errors.**
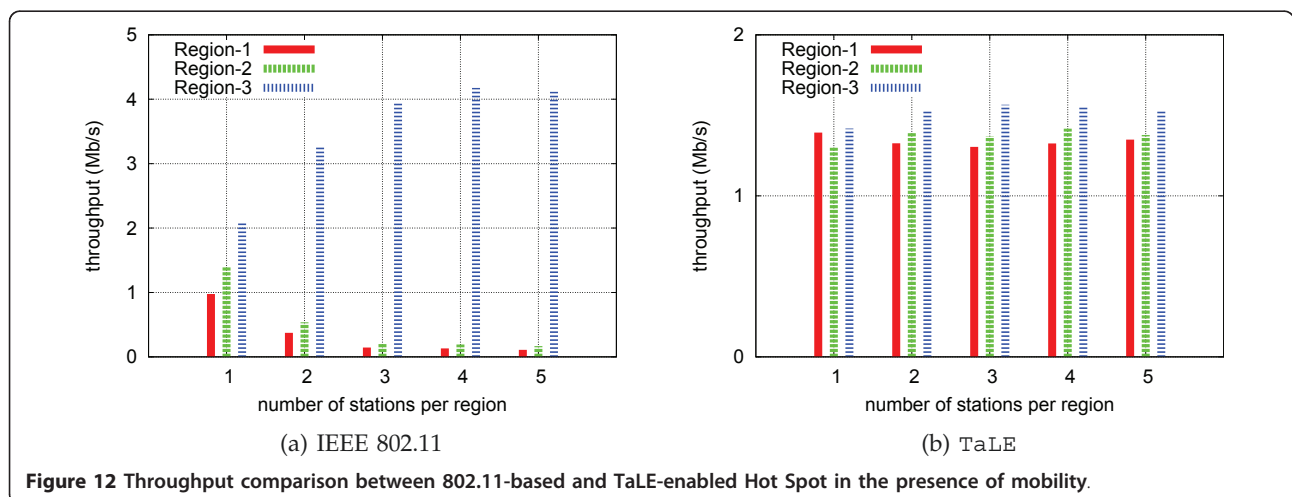
in both networks, the throughput of TaLE-enabled network is a little smaller than that of IEEE 802.11-based network due to the TaLE overhead resulted from broadcasting beacon frame to estimate channel state (Figure 13a). We however observe that TaLE-enabled network experiences significantly less loss rate than IEEE 802.11-network does (Figure 13b). Based on two metrics in Figure 13a and 13b, we can realize that the TaLE framework can reduce bandwidth waste used to retransmit lost frames, so that the effective throughput consequently increases.
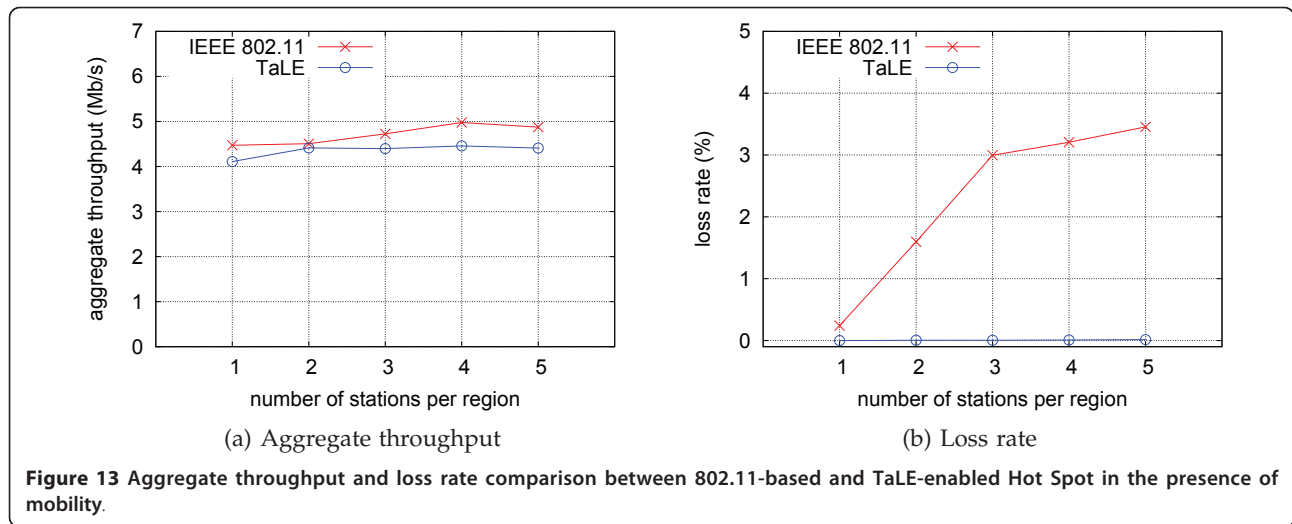
**Remark:** The performance metrics that we have used in this section show the superior performance of the proposed TaLE framework against that of the original IEEE 802.11-based network. This is because all the stations in a specific location cannot use more bandwidth than its allocated amount, which is decided by a given service differentiation ratio. The TaLE framework

installed at the AP actually enforces the differentiation together with the feedback control of TCP (or TCP-like) protocol. Even if wireless errors disrupt the data transmissions or some mobile scenarios appear (so that the available bandwidth is changed), the framework can redistribute the current available bandwidth according to the service differentiation since it continuously keeps track of the current state of the network bandwidth and the current locations of the mobile nodes. Note that all these aspects are embedded in Eq. (10).

### 6.3 Performance in case of heterogeneous station

In this section, we investigate the effect of the TaLE framework when each region has a different number of flows and each flow has different traffic properties. We use the following three different types of stations according to the property of their data flows instead of



(a) IEEE 802.11

(b) TaLE

**Figure 12 Throughput comparison between 802.11-based and TaLE-enabled Hot Spot in the presence of mobility.**

(a) Aggregate throughput

(b) Loss rate

**Figure 13 Aggregate throughput and loss rate comparison between 802.11-based and TaLE-enabled Hot Spot in the presence of mobility**.

`STS-1`, `STS-2`, and `STS-3` used in previous simulation studies:

- `Region-1` has a `TYPE-1` station, which conducts bulk download, and generates web-surfing-type traffic and also messenger-type traffic;
- `Region-2` has a `TYPE-2` station, which downloads bulk data;
- `Region-3` serves a `TYPE-3` station, which uploads its data.

Note that `TYPE-1` station has three flows, while others have a single flow. As for application traffic, we generate bulk download or upload traffic with FTP, web traffic with an exponential distributed traffic generator, and messenger traffic with a Pareto distributed traffic generator.

*6.3.1 Performance with respect to per-location throughput*
In this study, we employ the same simulation scenarios as used in Section 6.1.1 except that `TYPE-1`, `TYPE-2`, and `TYPE-3` stations are employed instead of `STS-1`, `STS-2`, and `STS-3`.

Figure 14 and Table 7 present throughput dynamics and average throughput of `TaLE`-enabled Hot Spot network. Note that we do not include corresponding results of IEEE 802.11-based network since the results show similar trends to those in Section 6.1 in the way that IEEE 802.11-based network provides neither fairness nor differentiation.

We observe from Figure 14 that `TaLE`-enabled Hot Spot network does not suffer from any unfairness when all the regions are assigned to the same weight and successfully provides service differentiation according to the given weights at the other case. Specifically, in the period of [20s, 40s], the average throughput of `Region-1` and that of `Region-2` are almost equal to each other

(2.04 and 2.10 Mb/s, respectively). Similarly, in the period of [40s, 60s], all the three regions use almost equal bandwidth. When different priorities are assigned to different Regions in the period of [60s, 120s], each region is entitled to use different network bandwidth according to the weight assigned to them. After `Region-2` stops serving `TYPE-2` stations at the instant of 140s, the `Region-1` and `Region-3` share the available bandwidth evenly in the period of [140s, 160s]. Consequently, per-location throughput for each region is nearly equal to each other when all the regions have the same weight, which reconfirms that per-location fairness achieved in the `TaLE` framework is almost immune to the number of flows and their traffic types. On the other hand, per-location throughput is differentiated according to per-location weight in the period of [60s, 120s]. In order to present those results in detail, Table 7 presents numerical results at each period. As already
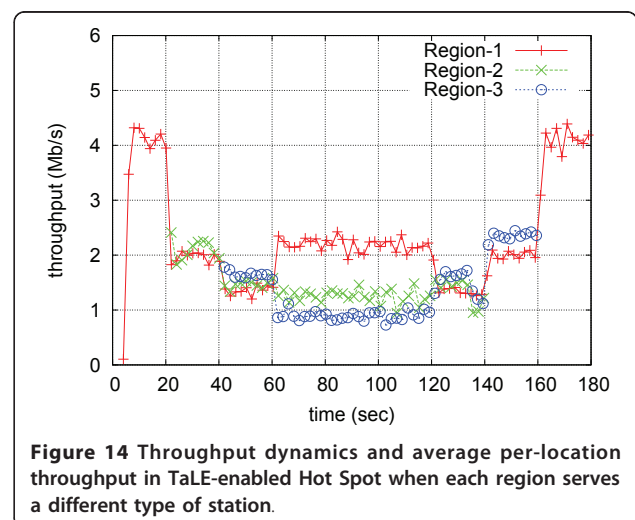


**Figure 14 Throughput dynamics and average per-location throughput in TaLE-enabled Hot Spot when each region serves a different type of station**.

**Table 7 Throughput dynamics and average per-location throughput in `TaLE`-enabled Hot Spot when each region serves a different type of station.**

| Time Interval | Region-1 (TYPE-1 STS) | Region-2 (TYPE-2 STS) | Region-3 (TYPE-3 STS) |
|---|---|---|---|
| [0s, 20s] | 3.95 | - | - |
| [20s, 40s] | 2.04 | 2.10 | - |
| [40s, 60s] | 1.30 | 1.51 | 1.65 |
| [60s, 120s] | 2.06 | 1.26 | 0.92 |
| [120s, 140s] | 1.30 | 1.36 | 1.48 |
| [140s, 160s] | 1.87 | - | 2.35 |
| [160s, 180s] | 3.92 | - | - |

**Table 8 Average per-location throughput of `TaLE`-enabled Hot Spot in the presence of wireless link errors.**

| Time interval | Region-1 (TYPE-1) | Region-2 (TYPE-2) | Region-3 (TYPE-3) |
|---|---|---|---|
| [0s, 20s] | 3.81 | - | - |
| [20s, 40s] | 1.87 | 2.03 | - |
| [40s, 60s] | 1.22 | 1.36 | 1.58 |
| [60s, 120s] | 0.94 | 1.15 | 0.86 |
| [120s, 140s] | 1.23 | 1.30 | 1.91 |
| [140s, 160s] | 1.73 | - | 2.28 |
| [160s, 180s] | 3.72 | - | - |

discussed with Figure 14, we observe that the `TaLE` framework can accurately support both service differentiation and fairness according to a given set of per-location weights for each period.

### 6.3.2 Performance in the presence of link errors

We then check whether or not the `TaLE` framework continuously supports the service differentiation when wireless link disrupts the wireless transmissions. We use the same simulation scenario as used in Section 6.3.1 for this study except what follows:

- there is no mobile scenarios for any station;
- all the regions are assigned to the same weight;
- wireless link errors specified in Section 6.1.2 appear in the period of [60s,120s].

Figure 15 and Table 8 present throughput dynamics measured in `TaLE`-enabled Hot Spot. Figure 15 shows that, even if wireless link errors are incurred in the `Region-1`, the service differentiation supported by `TaLE` framework is continuously working with a small throughput degradation at the erroneous region while
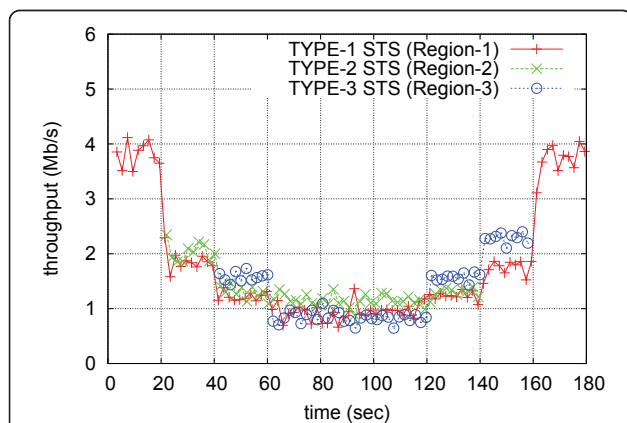
exiting IEEE 802.11-based network does not respond to the errors.

Table 8 compares in detail per-location throughput between IEEE 802.11-based and `TaLE`-enabled Hot Spot at each period when previously introduced two-state Markov-modulated wireless errors occurs at the Region-1.

### 6.3.3 Performance in the presence of mobility

We then verify whether the `TaLE` framework continuously supports the service differentiation when two stations, `TYPE-1` and `TYPE-3`, exchange their positions. We use the same simulation scenario as used in Section 6.1.3 for this study except that `TYPE-1`, `TYPE-2`, and `TYPE-3` are used instead of `STS-1`, `STS-2`, and `STS-3`.

Figure 16 and Table 9 present per-station throughput dynamics and average throughput of three stations in `TaLE`-enabled network. We observe that the `TaLE`-enabled framework supports distinct service differentiation agreeable to weights from Figure 16. Especially, in the period of [60s, 80s], the highest bandwidth is assigned to `TYPE-1` station since the highest weight is set to `Region-1`. Once `TYPE-1` station moves to



**Figure 15 Throughput dynamics of TaLE-enabled Hot Spot in the presence of wireless link errors.**
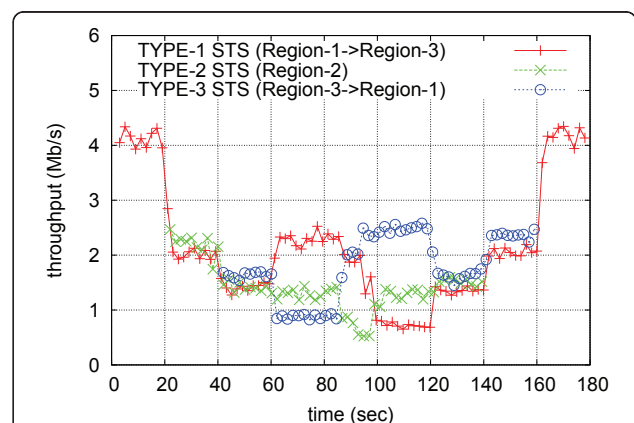


**Figure 16 Throughput dynamics in TaLE-enabled Hot Spot when TYPE-1and TYPE-3stations exchange their locations at the instant of 80s.**

**Table 9 Average per-station throughput in `TaLE`-enabled Hot Spot when TYPE-1 and TYPE-3 stations exchange their locations at the instant of 80s**

| Time interval | TYPE-1 STS | TYPE-2 STS | TYPE-3 STS |
|---------------|-----------|-----------|-----------|
| [0s, 20s]     | 4.10      | -         | -         |
| [20s, 40s]    | 1.99      | 2.20      | -         |
| [40s, 60s]    | 1.33      | 1.48      | 1.64      |
| [60s, 80s]    | 2.15      | 1.29      | 0.95      |
| [80s, 120s]   | 1.18      | 1.10      | 2.12      |
| [120s, 140s]  | 1.26      | 1.49      | 1.69      |
| [140s, 160s]  | 1.95      | -         | 2.32      |
| [160s, 180s]  | 3.82      | -         | -         |

`Region-3` and simultaneously `TYPE-3` station move to `Region-1` according to mobile scenario, `TYPE-3` station comes to use the highest bandwidth since its current location becomes `Region-1` with the highest weight. When all the regions come to have the same weight, i.e., the periods of [40s, 60s] and [120s, 140s], we can see all the regions use equal quantity of network bandwidth. Table 9 specifically enumerates per-station average throughput in `TaLE`-enabled Hot spot network at each period of simulation. Conclusively, even though different types of flows are served at each station and mobile scenario is presented, the simulation results indicate that the `TaLE` framework can provide the service differentiation according to per-location weight.

## 7 Conclusion

As location-based services (LBSs) become attractive services and are expected to be widely used, we need to directly use location information to provide service differentiation and/or fairness for them, which is completely different from existing per-station and per-flow service differentiation. In this paper, we have introduced `per-location target load` in order to support *location-based* service differentiation, then devised `Target Load Estimator (TaLE)` to determine current `per-location target load`, and finally proposed a `TaLE`-based framework of QoS provisioning in IEEE 802.11-based Hot Spot networks. In the `TaLE`-based framework, the AP keeps track of current per-location load diverged from a given per-location share of link capacity and its contribution to current network-wide load, and it feedbacks the load information to traffic senders. Based on the load information, each traffic sender adjusts its sending rate. We have implemented the proposed framework in *ns-2* simulator, and we carried out an extensive set of simulations to evaluate its performance with respect to fairness and service differentiation. The simulation results have indicated that the proposed `TaLE`-based framework can successfully

support both the per-location fairness and service differentiation, irrespective of the number of stations per location, station mobility, the number of flows per station, traffic types, and any combination thereof.

We have several directions for ongoing and future research. We plan to extend the `TaLE` framework to accommodate multi-hop cases with mobile scenarios and also extend it to accommodate other transport protocol, such as UDP, by designing an appropriate rate feedback control scheme. We then would like to build up an integrated framework of per-location, per-station, and per-flow QoS provisioning, adaptive to link status, traffic type and mobile scenario.

### Author details
[1]School of Electrical Engineering, Korea University, Anam-Dong, Seongbuk-Gu, Seoul 136-713, Korea [2]Department of Information & Communications, Dongguk University-Seoul, Korea [3]Department of Information and Communication Engineering, DGIST, Korea

### Competing interests
The authors declare that they have no competing interests.

### References
1. IEEE 802.11 WG, Part 11, Wireless LAN medium access control (MAC) and physical layer (PHY) specification, in *IEEE 802.11 Standard* (1999)
2. NTT DOCOMO, Ntt docomo i-mode. http://www.nttdocomo.com/services/imode/index.html
3. Sprint, Sprint navigation. http://navigation.sprint.com/snweb
4. Verizon, Verizen chaperone and navigator. http://products.vzw.com/index.aspx?id=fnd_toolsApps_childFinder
5. Federal Communications Commission (FCC), Fcc report to congress on the deployment of e-911 phase ii services by tier iii service providers (2005)
6. S Pilosof, R Ramjee, D Raz, Y Shavitt, P Sinha, Understanding TCP fairness over wireless LAN, in *Proceedings of IEEE INFOCOM* (2003)
7. E-J Lee, H-T Lim, S-J Seok, C-H Kang, A scheme for enhancing TCP fairness and throughput in IEEE 802.11 WLANs. In *Proceedings of IFIP NETWORKING* (2007)
8. Y Wu, Z Niu, J Zheng, Study of the TCP upstream/downstream unfairness issue with per-flow queuing over infrastructure-mode WLANs. Wirel. Commun. Mob. Comput. **5**(4), 459–471 (2005). doi:10.1002/wcm.303
9. X Lin, X Chang, JK Muppala, VQ-RED: An efficient virtual queue management approach to improve fairness in infrastructure WLAN, in *Proceedings of IEEE Local Computer Networks (LCN)* (2005)
10. J Ha, C-H Choi, TCP fairness for uplink and downlink flows in WLANs, in *Proceedings of IEEE Globecom 2006* (2006)
11. M Gong, Q Wu, C Williamson, Queue management strategies to improve TCP fairness in IEEE 802.11 wireless LANs, in *Proceedings of Workshop on Resource Allocation in Wireless Networks (RAWNET)* (2006)
12. N Blefari-Melazzi, A Detti, I Habib, A Ordine, S Salsano, TCP fairness issues in IEEE 802.11 networks: Problem analysis and solutions based on rate control. IEEE Trans. Wirel. Commun. **6**, 1346–1355 (2007)

13. DJ Leith, P Clifford, D Malone, A Ng, Tcp fairness in 802.11e wlans. IEEE Commun. Lett. **9**(11), 964–966 (2005). doi:10.1109/LCOMM.2005.11004
14. H Balakrishnan, VN Padmanabhan, S Seshan, RH Katz, Design of an enhanced access point to optimize TCP performance in Wi-Fi hotspot networks. Wirel. Netw. **13**, 259–274 (2007). doi:10.1007/s11276-006-6466-9
15. M Bottigliengo, C Casetti, C-F Chiasserini, M Meo, Smart traffic scheduling in 802.11 WLANs with access point, in *Proceedings of IEEE VTC-Fall* (2003)
16. S Kim, B-S Kim, Y Fang, Downlink and uplink resource allocation in IEEE 802.11 wireless LANs. IEEE Trans. Vehicular Technol. **54**, 320–327 (2005). doi:10.1109/TVT.2004.838887
17. M Ogawa, Y Kuno, T Sakata, S Kubota, MAC protocol for fair two-way communications in wireless LANs, in *Proceedings of International Conference on Parallel Processing Workshop (ICPPW)* (2005)
18. L Zhang, S Zeadally, A framework for efficient resource management in ieee 802.11 wlans. Wirel. Commun. Mob. Comput. **4**, 835–848 (2004). doi:10.1002/wcm.258
19. E-C Park, N Park, SK Lee, H Kim, Provisioning qos for wifi-enabled portable devices in home networks. Trans. Internet Inf. Syst. **5**, 720–740 (2011)
20. C-Y Chang, Y-C Chen, L-L Hung, S-W Chang, A novel multi-channel mac protocol with directional antenna for enhancing spatial reuse and bandwidth utilization in wlans. J. Parallel Distrib. Comput. **69**(10), 824–837 (2009). doi:10.1016/j.jpdc.2009.07.006
21. L Nogueira, LM Pinho, Time-bounded distributed qos-aware service configuration in heterogeneous cooperative environments. J. Parallel Distrib. Comput. **69**(6), 491–507 (2009). doi:10.1016/j.jpdc.2009.03.002
22. H Kim, JC Hou, Improving protocol capacity for UDP/TCP traffic with model-based frame scheduling in IEEE 802.11-operated WLANs. IEEE J. Sel. Areas Commun. **22**, 1987–2003 (2004). doi:10.1109/JSAC.2004.836008
23. M Demirbas, A Arora, V Mittal, V Kulathumani, A fault-local self-stabilizing clustering service for wireless ad hoc networks. IEEE Trans. Parallel Distrib. Syst. **17**(9), 912–922 (2006)
24. IEEE 802.11 WG, Part 11, Wireless LAN medium access control (MAC) and physical layer (PHY) specification: medium access control (MAC) quality of service (QoS) enhancements. *IEEE 802.11e/D6.0* (2003)
25. M Youssef, A Agrawala, U Shankar, Wlan location determination via clustering and probability distributions, in *Proceedings of IEEE PerCom 2003* (2003)
26. K Krizman, TE Biedka, T Rappaport, Wireless position location: fundamentals, implementation strategies, and source of error, in *IEEE VTC 1997* (1997)
27. S Wang, J Min, BK Yi, Location Based Services for Mobiles: Technologies and Standards, in *Proceedings of IEEE ICC 2008, (Beijing, China)* (2008)
28. 3GPP, 3gpp specifications. http://www.3gpp.com
29. 3GPP2, 3gpp2 specifications. http://www.3gpp2.com
30. Open Mobile Alliance (OMA), Oma location working group specifications. http://www.openmobilealliance.org
31. Internet Engineering Task Force (IETF), Set of request for comments (rfc) http://www.ietf.org
32. Peter Dana H, Coordinate systems overview. http://www.colorado.edu/geography/gcraft/notes/coordsys/coordsys_f.html
33. K Virrantaus, J Markkula, A Garmash, V Terziyan, J Veijalainen, A Katanosov, H Tirri, Developing GIS-supported location-based services, in *Proceedings of the Second International Conference on Web Information Systems Engineering 2001* (2001)
34. T D'Rosa, G Bilchev, An Overview of Location-Based Services. BT Technol. J. **21**, 20–27 (2003). doi:10.1023/A:1022491825047
35. R Bruno, M Conti, E Gregori, Analytical modeling of TCP clients in Wi-Fi hot spot networks, in *Proceedings of IFIP Networking* (2004)
36. S Choi, K Park, C Kim, Performance impact of inter-layer dependency in infrastructure WLANSs. IEEE Trans. Mob. Comput. **5**(7), 829–845 (2006)
37. E-C Park, D-Y Kim, H Kim, C-H Choi, Cross-Layer Approach for Per-Station Fairness in TCP over WLANs. IEEE Trans. Mob. Comput. **7**, 898–921 (2008)
38. K Ramakrishnan, S Floyd, A proposal to add explicit congestion notification (ECN) to IP. *IETF RFC 2481* (1999)
39. A O'Dwyer, *Pi and pid control tuning rules for time delay processes: a summary*, in *Dublin Institute of Technology, Ireland, Technical Report AOD-01-01* (2001)
40. D-M Chiu, R Jain, Analysis of the increase and decrease algorithms for congestion avoidance in computer networks. Comput. Netw. ISDN Syst. **17**, 1–14 (1989). doi:10.1016/0169-7552(89)90019-6
41. S Rayanchu, A Mishra, D Agrawalx, S Saha, S Banerjee, Diagnosing wireless packet losses in 802.11: Separating collision from weak signal, in *IEEE INFOCOM 2008* (2008)
42. C Reis, R Mahajan, M Rodig, D Wetherall, J Zahorjan, Measurement-based models of delivery and interference in static wireless networks, in *ACM SIGCOMM 2006* (2006)
43. A Kashyap, S Ganguly, SR Das, A measurement-based approach to modeling link capacity in 802.11-based wireless networks, in *ACM MobiCom 2007* (2007)
44. L Qiu, Y Zhang, F Wang, M Han, R Mahajan, A general model of wireless interference, in *ACM MobiCom 2007* (2007)
45. AC Ng, D Malone, DJ Leith, Experimental evaluation of TCP performance and fairness in an 802.11e test-bed, in *Proceedings of ACM SIGCOMM workshop on Experimental Approaches to Wireless Network Design and Analysis* (2005)