On Exploiting Location Information for Service Differentiation in IEEE 802.11 Hot Spots

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Abstract—In this paper, we propose a feedback framework of providing fairness and service differentiation according to location information for TCP traffic in IEEE 802.11 Hot Spots. In the framework, we introduce location access price (LAP) to denote both the network-wide and per-location channel utilization, which is delivered to TCP senders and used to adjust their sending rate. We implemented the proposed framework in ns-2 simulator, and conducted a simulation study so as to evaluate its performance. The simulation results indicate that the proposed framework can provide location-based service differentiation in IEEE 802.11 Hot Spots.

I. INTRODUCTION

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 this, the last-mile extension in campuses, restaurants, and convention centers, IEEE 802.11-enabled portable devices and consumer electronics have also started to be available in home networks for uploading and/or downloading multimedia contents to/from a home-gateway through the wireless medium.

On the other hand, wireless Internet service providers (WISPs) recently implemented and launched location-based services (LBS) owing to the availability in location measurement technologies and the noticeable advancement in personal navigational aids and tracking services. LBS gives WISPs the ability of tailoring available information and services to user’s preference by using location information. LBS (i) personalizes information services based on location device components (which pinpoint user’s location), and provides a list of service/contents providers available within user’s proximity; (ii) provides different rate, i.e. flat-rate, special and discount rate for customers in accordance with their current location, such as private location, home location, or work location; (iii) identifies emergent events and provides privileged access for tracking the emergency situation and providing relevant services.

In this paper, we propose a framework of service differentiation to support LBS in IEEE 802.11-based Hot Spots. Even though there are some solutions to support Quality of Services (QoS), such as IEEE 802.11e, they are not appropriate for the differentiation in LBS since they just focus on per-flow or per-station QoS scheme without considering and exploiting location information. Suppose Fig. 1 depicts a network configuration where Station 1 uses bulk download (FTP) while Station 2 does bulk upload. The main problem that we address in the figure is how to give higher priority to stations in Region 1 than any station in Region 2, regardless of per-station and/or per-flow characteristics. Fig. 2 presents the results obtained when we use the IEEE 802.11 protocol. From the figure, we observe the followings: (i) IEEE 802.11-based networks impose unfairness on downloading station (denoted by DN STS) compared to uploading station (denoted by UP STS) due to TCP-driven unfairness [2], [3], [4]; Specifically, DN STS only uses 1.45 Mb/s while UP STS enjoys 2.99 Mb/s in the period of [20s, 140s]; (ii) there is no service differentiation according to location.

If we use one of solutions presented in Section II, we need to identify each flow and its originating location, or discover where the station is and then what flows belong to it, in order to implement a location-based framework of service-differentiation. Taking a departure from the per-flow or per-station schemes, we propose a new aspect of service differentiation, which is driven by location information, for TCP traffic in IEEE 802.11 Hot Spots. Thus, we can assign per-location priority instead of per-station or per-flow in the wireless networks.

In order to impose priority on location, we partition AP coverage into several locations, various from a single point to a region, and then set different priority to different locations. Then AP continuously keeps track of per-location channel-usage and network-wide traffic load, estimates Location Access Price (LAP) (that represents both the information), and feedback the LAP to TCP senders. TCP sender adjusts its sending rate according to the LAP. 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 it provides per-location service differentiation, even in mobile environment. Note that the AP is assumed to know all the positions for all the participants within the network. This can be possible with GPS or any other positional device or infrastructure. To the best of our knowledge, this is the first attempt to exploit location information to provide a service differentiation in IEEE 802.11 Hot Spots. We believe the proposed scheme is very appropriate for supporting a QoS scheme for LBS in wireless networks.

The rest of the paper is organized as follows. In Section II we summarize previous work related to the unfairness in WLANs. We propose a framework of QoS provisioning based on Location Access Price in Section III, validate the framework in Section IV, and present the simulation results in Section V. Finally, we conclude the paper with Section VI.

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II. RELATED WORK

In this section, we briefly introduce previous work to achieve fairness and/or service differentiation in IEEE 802.11 WLANs.

The fairness in TCP over WiFi Hot Spots has been recently investigated in [5], [6], [7], [8]. In [5], it has been demonstrated that AP favors uplink TCP flows more than downlink TCP flows and that its buffer capacity influences on the fairness among stations. The proposed solution is that the AP directly manipulates the advertised TCP window size in TCP ACK packets passing through it. The approach presented in [6] is to carry out per-flow scheduling at the AP in the network, but it imposes considerable complexity on the AP. Dual queue at the AP has been proposed in [7]; one is for TCP data packets and the other for TCP ACK packets, and both queue are scheduled according to an appropriate probability. The service differentiation scheme in IEEE 802.11e [9] is employed in [8] in order to achieve the fairness. Different inter-frame space, contention window size, and transmission opportunity (TXOP) are specified for TCP data and ACK packets. The recent work in [2], [3] have investigated the inter-dependency between TCP and MAC layer in Hot Spots. According to them, TCP congestion control scheme governs the number of contending stations at MAC layer. Additionally, the unfairness among stations has been examined also in [4] and then a per-station solution has been proposed based on a channel access cost in its subsequent work [10].

Some solutions for supporting the fairness among sending and receiving stations have been proposed [11], [12], [13]. The approach in [11] mitigates the unfairness by reducing the chances of transmission for the sending stations in the way of increasing the minimum contention window size in those stations. The downlink compensation access (DCA) algorithm in [12] gives higher priority to the AP with smaller inter frame space. In [13], each sending station defers its access based on the next packet information. All these schemes in [11], [12], [13], based on MAC scheduling, cannot always guarantee the fairness at TCP (or TCP-like) transport protocols, which is different from work in [5], [6], [7], [8].

Several MAC protocols have been proposed to achieve fairness in WLANs [14], [15], [16], mainly focusing on the issue of giving fair access chances to competing stations. These work however cannot assure the fairness among (sending and receiving) stations in WLANs.

As aforementioned in Section I, we focus on location information, and implement a service differentiation according to the information. The proposed solution can also address in part the unfairness between uploading and downloading station.

III. LOCATION ACCESS PRICE FEEDBACK APPROACH

In order to implement location-based service differentiation, we devise Location Access Price (LAP), which represents the network-wide traffic load and per-location channel-usage. The details on how to use and estimate LAP will be accounted for in what follows.

- Once a packet (TCP data or ACK packet) arrives to AP, the LAP estimator randomly chooses a number between zero and one, and compares it with the previously computed price: if the number is less than the price, it marks a single bit of LAP (for which we use one bit from the undefined subtype of frame control field) in the MAC header. Thus, the price is piggybacked on the data frame from the AP to a station.
- On receiving a packet whose LAP bit is set, the station should deliver the information to the transport layer. If the IP layer sees LAP bit (in MAC header) set, it marks the ECN bit [17] in the IP header. If the station is a receiver, the LAP bit is returned to the corresponding sender via the TCP ACK packet.
- Finally, the TCP sender recognizes LAP and adapts its congestion window.

The LAP estimator, positioned at the link layer of AP, monitors traffic load and channel usage, and updates the LAP to provide differentiation among location and avoid buffer overflow at the AP. The access price for the ith location, \( P_i \), includes two constituent prices: (i) the per-location access price for the ith location, \( P_i^t \), to estimate per-location channel usage; (ii) the network-wide access price for the network, \( P^w \), to estimate network-wide load, so that it is expressed with

\[
    P_i(t) = (P_i^t(t) + P^w(t))^+, \quad t = n \cdot T_{int},
\]

where \((\cdot)^+\) denotes the largest non-negative value but less than or equal to 1.

The similar notion is used in [10] to support per-station fairness, but note that the proposed framework introduces the price to estimate per-location channel-usage.
**Per-Location Access Price:** In order to assure location-based service differentiation for LBS when each location has a different number of stations, each station has a different number of flows, and each flow has a different transmission rate, we explicitly include per-location access price $P_l^i$ in (1).

The key idea of computing $P_l^i$ is to give positive or negative incentive to a specific location that has accessed wireless channel more/less than its fair access time, $T_{fair}$, during a given channel monitoring interval, $T_{mon}$. Note that the LAP estimator at the AP can monitor channel access time for each location because all traffic traverses the AP. If the channel is shared by $N$ locations, we set $T_{fair} = T_{mon}/N$.

During every interval, $T_{mon}$, of monitoring the channel, the LAP estimator estimates the channel access time $t_i$ for the $i$th location. Whenever the AP sends/receives a data frame for any station at the $i$th location, LAP increases $t_i$ by the amount of $t_{ov} + \ell/r$, where $t_{ov}$ is the overhead time to transmit a data frame and the corresponding MAC-layer ACK frame (RTS and CTS frame when the RTS/CTS is enabled), inclusive of inter-frame spaces and backoff time, $\ell$ and $r$ denote the frame size and transmission rate, respectively.

With channel access time $t_i$ and fair access time $T_{fair}$, LAP calculates $P_l^i$ to assure per-location fairness. Let $t_i[m]$ and $P_l^i[m]$ denote the channel access time and per-location access price of the $i$th location at the $m$th monitoring interval, i.e., $t = m \cdot T_{mon}$, respectively. Then, $P_l^i[m]$ is calculated as

$$P_l^i[m] = \begin{cases} \mathcal{K} \cdot t_{i[m-1]} - T_{fair} / t_{i[m-1]} & \text{if } t_{i[m-1]} > 0 \\ \mathcal{K} & \text{otherwise} \end{cases}$$

where $\mathcal{K}, 0 < \mathcal{K} \leq 1$ is a scaling parameter. If all the stations at $i$th location have accessed the channel excessively in the previous monitoring interval, i.e., $t_i[m-1] > T_{fair}$, then LAP increases the access price for them by $P_l^i[m]$ at the current interval. Otherwise, if $t_i[m-1] < T_{fair}$, LAP decreases its access price and compensates any station at the $i$th location for the less channel access opportunity in previous interval.

**Network-wide Access Price:** The network-wide access price, $P^w$, is included to reduce packet loss due to buffer overflow and to maximize channel utilization. The goal of $P^w$ is to tightly regulate the queue length to a target value, and to match the aggregate input rate with the network capacity.

Let $r[n]$ and $r_{ref}[n]$ denote the aggregated input rate of packets to the queue and the virtual target rate, respectively, at the $n$th update instant, i.e., at time $t = n \cdot T_{int}$. Based on the difference between $r[n]$ and $r_{ref}[n]$, the price $P^w[n]$ is determined as

$$P^w[n] = \alpha (r[n] - r_{ref}[n]),$$

where $\alpha(> 0)$ is a control gain. Note that the price increases accordingly as $r[n]$ exceeds $r_{ref}[n]$. In order to regulate the queue length, $q[n]$, to the desired value $q_{ref}$, the virtual target rate $r_{ref}[n]$ is updated as

$$r_{ref}[n] = C[n] - \beta(q[n] - q_{ref}) - \Delta r_{ref}[n],$$

$$\Delta r_{ref}[n] = \Delta r_{ref}[n-1] + \gamma (T_{int}(r[n] - C[n]) + \beta(q[n] - q_{ref})).$$

Additionally, we remove the term of $(r[n] - C[n])$ with:

$$q[k] - q[k-1] = T_{int}(r[k] - C[k]).$$

With (3)–(6), the LAP algorithm can be easily implemented only with the information of queue length, without estimating the input rate or channel capacity as

$$P^w[n] = \alpha \left( (\beta + \gamma + \frac{1}{T_{int}})q[n] - \frac{1}{T_{int}}q[n-1] - \beta q_{ref} + \beta \gamma \sum_{k=0}^{n} (q[k] - q_{ref}) \right).$$

Note that while $P^w$ is updated at every interval of $T_{int}$, $P_l^i$ is decided at every interval of $T_{mon}$.

**IV. VALIDATION**

We firstly show that LAP-enabled WLAN solves the problem of unfairness and service differentiation presented in Figs 1–2. In order to present that LAP-enabled WLAN achieves both the fairness and service differentiation, we use the following simulation scenarios:

- **DN (Download) station** is active throughout the whole period of [0s, 160s] and continuously downloads data from the server, denoted wired STS directly connected to AP as in Fig. 1;
- **UP (Upload) station** arrives at the time instant of 20s, starts to upload its data to the server via the AP, and then leaves at the time instant of 140s;
- **Region 1** and **Region 2** have the same priority of 1 initially;
- **Region 1** comes to have the priority of 4 in the interval of [40s, 80s], and returns to 1 immediately after the interval;
- **Region 2** starts to use the priority of 4 in the interval of [80s, 120s], and returns to 1 at the instant of 120s.

Note that the higher number represents the higher priority. In addition, since all the stations hear each other, there is little concern for hidden terminals, and the RTS/CTS mechanism is not enabled. 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 1000 bytes. The parameters of the LAP scheme, $\alpha$, $\beta$, $\gamma$, and $\mathcal{K}$, are set to 0.0003, 0.02, 8, and 0.85, respectively, and the interval of monitoring channel $T_{mon}$ for per-location access price and that of updating access price $T_{int}$ for network-wide access price are set to 10 ms and 10 ms, respectively. These settings are continuously effective for the subsequent simulation study in Section V.

From Fig. 3, we can observe that LAP enforces fairness among two stations when two priorities are equal, regardless of uploading or downloading, shown in periods of [20s, 40s] and [120s, 140s]; in specific, DN station achieves 1.73 (1.69
Mb/s) in the period of [20s, 40s] ([120s, 140s]) while UP station uses 1.72 (1.75 Mb/s) in the corresponding period, which means that the proposed LAP framework achieves the fairness. Also we can see that it gives service differentiation between two stations according to the priority given to each region. In the period of [40s, 80s], UP station in Region 1 uses about 2.85 Mb/s while DN station in Region 2 does about 0.75 Mb/s, but when we exchange priorities between Region 1 and 2, the ratio of throughput in Region 1 and 2 becomes reversed; in specific, DN station exploits 2.5488 Mb/s but UP station uses 0.8455 Mb/s. Therefore, the proposed framework also supports service differentiation.

V. SIMULATION STUDY

In this section, we conduct a ns-2 simulation study with more various perspectives so as to demonstrate the properties of the LAP framework. We use a wireless LAN in Fig. 4. Additionally, we use the following three different types of stations according to the property of their data flow (s), each of which communicate with its corresponding station two hops (consisting of one wired and one wireless hop) away from it. Note that capacity and delay for each link is specified in the figure:

- TYPE 1 station resides in Region 1, and conducts FTP or P2P download, web-surfing, and messenger;
- TYPE 2 station resides in Region 2, and downloads multimedia data;
- TYPE 3 station resides in Region 3, and uploads its data.

Note that TYPE 1 station has three connections, while others have a single connection. As application traffic, we generate bulk download or upload traffic with FTP, web-traffic with an exponential distribution, and messenger traffic with a Pareto distribution. The AP coverage (100 m × 100 m) is divided into three regions, and one station of each type is initially placed in each region.

A. Performance with respect to per-location throughput

In this study, we investigate the service differentiation among stations, by comparing IEEE 802.11-based stations and LAP-enabled stations. The simulation scenarios are as follows:

- a TYPE 2 station arrives at the time instant of 20s, starts to download data, and then leaves at the instant of 140s;
- a TYPE 3 station uploads its data to the AP during the interval of [40s, 160s];
- the Region 1, 2, and 3 are initially assigned to the same priority of 1;
- the Region 1, 2, and 3 are assigned to highest priority (4), the middle one (2), and the lowest priority (1), individually, during the interval of [60s, 120s].

Fig. 5 compares IEEE 802.11-based WLAN and LAP-enabled WLAN with per-location throughput. In the period of [20s, 40s] when no uploading station (TYPE 3) appear yet, IEEE 802.11-based WLAN gives no considerable discrepancy between two types of downloading stations (TYPE 1 and TYPE 2). When TYPE 3 station starts to upload data at the instant of 40s, it dominates to use network bandwidth in the period of [40s, 180s]. The throughput of TYPE 1 and TYPE 2 stations are significantly degraded in this period.

On the contrary, LAP-enabled WLAN does not suffer from the unfairness. Fig. 5 (b) presents that all the stations successfully achieve both the fairness and service differentiation, regardless the number of active stations and their types at each period. In the period of [20s, 40s], the average throughput of TYPE 1 and TYPE 2 stations are almost equal to each other (2.11 and 2.13 Mb/s, respectively). Similarly, in the period of [40s, 60s], all the three stations share the bandwidth evenly. When different priorities are assigned to different regions in the period of [60s, 120s] (according to aforementioned simulation scenario), each station exploits different network bandwidth according to the priority assigned to the Region in which it resides. After TYPE 2 station leaves the network at the instant of 140s, the remaining TYPE 1 and TYPE 3 stations share the available bandwidth evenly in the period of [140s, 160s]. Consequently, per-location throughput in the period of [20s, 40s], [40s, 60s], [120s, 140s], and [140s, 160s] are nearly equal, which reconfirms that per-location fairness achieved in the LAP framework is almost immune to the number of stations and their types, and per-location throughput is differentiated according to per-location priority in the period of [60s, 120s].

B. Performance in the presence of mobility

As mentioned in Section I, the LAP framework achieves per-location service differentiation instead of per-flow or per-station one. Now, we investigate the effect of mobility on LAP framework. We use the additional mobile scenario to the scenario used in Section V-A, which is:
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VI. CONCLUSION

In this paper, we proposed a location-based framework of QoS provisiong for TCP traffic in IEEE 802.11 Hot Spots. In the framework, the AP keeps track of per-location channel-usage and network-wide load, and estimates Location Access Price (LAP) to feedback to TCP sender. Based on the LAP, each TCP sender adjusts its sending rate. We implemented the proposed framework in ns-2 simulator, and carried out a set of simulations to evaluate its performance with respect to fairness and service differentiation. The simulation results indicate that the proposed framework can successfully support both the per-location fairness and service differentiation. We plan to extend LAP framework to accommodate multi-hop cases and consider the erroneous situation, and extend it to accommodate other transport protocol without feedback control, such as UDP.

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