LIES: Location Information Based Enhancements in Wireless Systems

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1 Introduction

The rapid growth in the number of smart-phones and accompanying wireless services is driving users' ever-increasing demand for more data (particularly video) and shorter data-delivery times. From a systems standpoint, this has led to the development of "Increasing Data Requirements" (IDR). To date, wireless systems have tried to support IDR by evolving more efficient wireless communication technologies (e.g., GSM → WCDMA → HSDPA → LTE → LTE-advanced). In this proposal, we will instead address the issue of supporting IDR by leveraging a rich source of side information that can readily be made available to system designers: location.

Current mobile devices are capable of transmitting and/or receiving data via a variety of wireless technologies, including Wi-Fi, Bluetooth, GSM/WCDMA/LTE, and GPS. We propose building upon the integration of one or more of these technologies to expose huge opportunities in wireless system design to support IDR. Stated succinctly, we propose the following:

> *"Exploit periodically obtained location information about mobile terminals at a base-station to predict performance and initiate system optimization actions, such as preemptive handoffs in urban-canyon environments and cell-breathing."*

Let us demonstrate how this is useful via two examples.

Example 1. *Suppose John is in a moving car and is on a voice call with his friend via his mobile phone. If the car passes through a hilly region (such as in San Diego) or between tall buildings (such as in New York/Chicago), John will experience sudden degradation in the connected base-station's signal due to the appearance of these large obstacles. In such cases, calls will frequently drop (especially VOIP calls). To circumvent this problem, John's phone must change its serving base-station quickly, which may not be possible if the car is moving at high speeds. On the other hand, if the base-station knows the location of urban-canyons in its vicinity*[1]*, this information, along with the knowledge of the location of the mobile device, would enable a preemptive handoff to a base-station or microcell positioned to cover the urban canyon. Since the location of John is known to the base-station, it can predict when John will pass through the urban-canyon and initiate a serving-cell change before he enters it. By sharing location information, John can expect to encounter far fewer call drops, regardless of terrain!*

In the following example, we illustrate how location-aware management of mobile device connectivity can improve overall network performance. The example is applicable to current as well as future cellular network standards and requires almost no additional infrastructure and minimal protocol overhead.

Example 2. *Consider a network where a closed femtocell covers a certain area which is also covered by a macro base-station for that region. All user devices can be served by the macro base-station, while only a subset of devices can be served by a femtocell. Let us denote a device that can be served by both the macro base-station and femtocell by the acronym HUE (Home User Equipment) and a device that can be served only by the macro base-station by the acronym MUE (Macro User Equipment). To begin with, assume the HUE and MUE are being served by the macro base-station and both are moving closer to the femtocell.*

System Innovation 1: *If the base-station knows the location of the HUE, it can reduce the power allocated to the HUE deliberately when it approaches the femtocell. This will result in the HUE switching its serving-cell to the femtocell and thus increase capacity offloading from the base-station. Once the HUE switches over, another MUE can be served by the base-station, thereby increasing capacity and user-satisfaction.*

[1] This information can be learned automatically by aggregating historical signal levels as a function of geographical location.

System Innovation 2: *If the base-station knows the MUE location, then when the MUE moves closer to the femtocell, the base-station can increase the power allocated to the MUE to overcome interference. In current systems this is typically done by feeding back the received power levels from the users to the base-station using frequent pilot sequences. The feedback of location information to the base-station need not occur as frequently, and hence the net amount of feedback transmitted to the base-station can be significantly reduced. Furthermore, by knowing the location of the MUE, the base-station can improve the reliability of its handoff algorithms when it is time for the MUE to switch to another base-station.*

The preceding examples demonstrate some of the implications of our idea in radio network management, system innovations, and radio signal propagation and processing. In addition, our proposal offers additional opportunities in areas that extend beyond the traditional concerns of wireless service providers. We now highlight several such opportunities.

As energy resources become more tightly constrained, cities are placing an increased emphasis on transportation planning and forecasting. Critical to both short- and long-term planning is the acquisition of reliable data on the behavior patterns of commuters and the status of transportation infrastructure. Acquiring this data is challenging and costly for municipalities. A wireless service provider that has nearly instantaneous knowledge of the location of devices within a region can provide a valuable service to planners and forecasters by conveying information about, e.g., traffic speeds along major arteries, traffic flow volume, bottlenecks, and aggregate usage patterns. Delivering this information can serve as an additional revenue stream for service providers, and yield invaluable insights to city and regional planners.

Location information obtained by service providers can also be extremely useful to emergency management personnel during disasters and catastrophes. Given the ubiquity of wireless devices, particularly mobile phones, knowledge of the location of such devices serves as a reasonable proxy for the location of victims within a disaster region. Even if communication infrastructure becomes disabled during an emergency, location information prior to service disruption can aid first responders in prioritizing their search and rescue efforts, particularly in rural and remote areas.

A third important benefit provided by location information is in network coverage and capacity planning. By better understanding the geographical usage patterns of their customers, wireless service providers can prioritize infrastructure upgrades that will provide coverage and capacity improvements to the greatest number of users. Additionally, location information will give service providers a better understanding of where gaps in their coverage lie, enabling them to add pico- or microcells as needed.

2 Implementing Location-Aware Services

In this section, we illustrate the issues in implementing our approach with cellular phone technology since it is arguably the most complex and prevalent wireless system. The mobile-wireless industry is undergoing a huge growth in communication infrastructure (particularly in the number of transmitters), such as wireless routers, GPS satellites, base-stations, and femtocells. At the same time, traditional mobile phones are increasingly being replaced by smart-phones that use an array of technologies to transmit/receive data. For example, GPS/aGPS triangulation is used for navigation, Wi-Fi is used for data communication over a local area network (LAN), and cellular communication (GSM/WCDMA/LTE etc.) is used for voice/video/data services. This explosive growth has introduced new complex challenges such as load balancing, capacity offloading, and interference management in wireless system design. As illustrated by the previous examples, knowledge of user locations at the base-stations can assist in implementing numerous wireless system enhancements. Here, we address two main issues in implementing location-aware services — viability and security.

- **Viability:** Current mobile-phones use GPS/aGPS (or both) to find their location for navigational purposes and advanced application features. Clearly, if the users find their location (latitude and longitude coordinates) at regular intervals, they can send this location information to wireless base-stations as additional protocol overhead. We illustrate that the overhead required is minimal using the following example:

Consider a time-slotted HSDPA system where each time-slot is of duration 2 *milliseconds, and hence resource allocation and scheduling occurs every* 2 *milliseconds. Now, if a mobile-user is moving at a speed of* 200 *kph (*125 *mph) on a high-speed railway, it covers a distance of* 1 *meter in* 18 *milliseconds, i.e.,* 9 *time-slots. Hence, if the location information is sent by the user to a base-station every* 9 *time-slots, the base-station can determine the location and speed of the user with high accuracy (here, up to* 1 *meter). With reference to Example* 1*, we note that typical distances that can cause substantial degradation in a mobile-user's signal due to the presence of large obstacles (hills, tall buildings, etc.) vary from a few meters to tens/hundreds of meters. Hence, the overhead of communicating location information every* 9 *time slots is sufficient*[2] *for ascertaining the location and velocity of the user at the base-station (which, in turn, helps in implementing preemptive handoffs to avoid packet-drops).*

Even without the availability of GPS/aGPS, there is extensive literature on acquiring location information at regular intervals by exploiting correlation properties of shadow-fading in radio-link measurement data [1].

The location information of users can be sent to the base-stations by setting up a dedicated control uplink channel (or using existing uplink control channels in certain wireless standards) to send user-location information to nearby transmitters. Current wireless systems allow coordination amongst base-stations (or, with other transmitters such as femtocells), and thus it is safe to assume that if one base-station knows the location of a user, this information can be sent to other base-stations via a wired backhaul network.

- **Security:** Any technology that proposes to track the location of users requires a thoughtful consideration of privacy and security issues, and our proposal is no exception. Giving users the option to opt in or out of providing location information to their service provider through a software mechanism on their mobile device is perhaps the most transparent and simple way of allowing users to decide what, if any, information they choose to share with their service-provider. For users, the benefit of providing this information comes in the form of increased reliability, and higher data-rates. In addition, many of the location-based services (examples $1, 2$ in previous section) only require short-term storage at a handful of base-stations to implement system optimization actions. Long-term storage of location information (for generating aggregate usage pattern data for network design purposes) can be made anonymous to minimize the risk of any personally-identifiable information being divulged.

References

[1] H.-P. Lin, R.-T. Juang, and D.-B. Lin, "Validation of an improved location-based handover algorithm using GSM measurement data," IEEE Transactions on Mobile Computing, vol. 4, no. 5, pp. 530-536, Sept.-Oct. 2005.

[2] Indeed, this hypothetical example is quite conservative, since users traveling at high speeds typically follow predictable trajectories over short distances. Simple prediction algorithms could be employed to provide reliable estimates of user locations and trajectories over small time intervals, further reducing the overhead required to transmit location information.