# Enhancing Cellular Infrastructures: A Reflective Approach

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## ABSTRACT

In this paper, we make a case of a reflective architecture for cellular systems as means to support flexibility and evolvability of the existing cellular network infrastructure to deal with a new generation of adaptive environments and applications. Existing systems are event/request driven and mechanisms to enable seamless adaptivity are limited. We show how the various proposed (but largely unimplemented) dynamic adaptation techniques for existing networks (GSM / CDMA) can be incorporated into a Reflective Cellular Architecture (RCA). Self representation in the RCA enables a new class of proactive and prediction-based information driven algorithms. We illustrate how the RCA enables novel techniques for observation and management of information in cellular networks, use the observed information in the design of effective coarse and fine grained location prediction meta-level services. We further illustrate how such meta-level services can be used to enhance the capabilities of today's cellular networks ranging from better radio resource management of the cellular infrastructure and customized alerting in disasters to effective utilization of other coexisting networks.

## Keywords

Cellular network, Adaptation, Reification, Location prediction

## 1. INTRODUCTION

According to a recent estimate, there are currently over 5 billion mobile phone subscribers around the world. The popularity of cellular phones has clearly established the willingness of people to carry with them a versatile device, capable of communication, as well as computation and storage. This situation is being exploited by the market to create a multitude of information services aimed at improving end-user experience and/or offering functionalities that would not be possible otherwise. Examples include location based services, capture and delivery of multimedia content, personal sensing and health monitoring, the ability to communicate with smart spaces, connecting with home sensors for surveillance, and alerts which inform the owner of an abnormal event via short-message-services (SMS) sent to his cell phone.

Given the popularity and pervasiveness of cellular technology, we believe that it can play a unique and vital role for large scale information centric applications that collect, analyze, share and disseminate information in a variety of situations. This enables a new view of the cellular infrastructure as a network of sensors that collects and provides information about the execution environment; raw information thus obtained from individual users can be used to create a broader view of the current system both spatially and temporally. The view promotes a new class of applications that support information/data driven decision making that utilizes the captured spatiotemporal data. For example, resource allocation in the network can be proactively adapted to changing information about the needs of applications utilizing the network instead of a reactive approach where users and systems respond to degradations in service.

Today, cellular infrastructures are designed and deployed in a somewhat rigid fashion based on expected usage scenarios. Once deployed, usage data is frequently collected to determine if the deployment meets the usage requirements and (if not) how the system can be adapted/modified to meet the user needs. Such a *design-deploy-analyze* paradigm is not well suited to support the changing needs of new resource intensive applications that expect consistent service despite changing network and user conditions. The slow turnaround times also do not scale to unpredictable and/or extreme situations such as those that arise during a crisis. It is no surprise that cellular services are amongst the first ones to fail due to both traffic overload and physical infrastructure failures during such events since their current designs are not conducive to dynamic adaptation of user applications or infrastructure services. What is required is a transition to *design-develop-observe-adapt* cycle, similar to that proposed for network architectures [2], where conditions internal to network and system components are observed to enable analysis and dynamic reconfiguration.

Through a detailed study of current adaptations in GSM and CDMA networks, we argue that a reflective architec-


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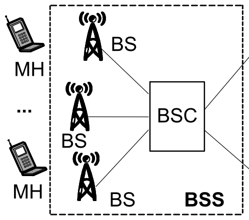



**Figure 1: Overview of cellular infrastructure.**

ture can not only provide a framework for incorporating existing adaptive solutions, but can also enable novel adaptations and applications that can significantly expand the scope and utility of the cellular infrastructure (Section 2). In particular, we develop a meta-architectural model of cellular systems and show that emerging applications may not necessarily require restructuring the network and its components, but a change in the way information is observed, gathered and used. In Section 4, we develop a flexible location management/prediction metalevel service using information observed through our RCA framework and illustrate concrete use cases of the developed metalevel service.

## 2. A META ARCHITECTURE FOR REFLECTIVE CELLULAR ARCHITECTURE

Current cellular network technology is implemented using two major standards - GSM and CDMA. Figure 1 shows the basic components of GSM and CDMA based cellular systems. Mobile hosts (MH) communicate with a base station (BS); a base station controller (BSC) manages multiple BS's and connects them to other parts of the infrastructure. The base station subsystem (BSS) processes voice calls from other mobile hosts or from other users on the Public Switched Telephone Network (PSTN) through Mobile Switch Centers (MSCs). In the GSM system, Serving GPRS Support Nodes (SGSN) and Gateway GPRS Support Nodes (GGSN) help route the data packets from MSCs to public data networks (e.g. Internet). In a CDMA network, data packets are routed to public data networks by MSC directly. In the traditional view of cellular systems, network components (base stations, controllers etc.) create and manage communication networks, allocate network resources, and provide different cellular services to the end users. Users on handsets are end-consumers of resources and services obtained from the service provider.

In this paper, we propose Reflective Cellular Architectures (RCA) - an adaptive way of structuring, managing and using cellular networks by exploiting the notion of computational reflection. Computational reflection [1] is an acknowledged technique for dealing with dynamic reconfiguration in adaptive environments where the system maintains a causally-connected representation. This has been applied in a variety of contexts including distributed multimedia, programmable networks, component-based software development, adaptively composable middleware [16, 11], grid computing, peer-oriented networks and mobile distributed systems. Past efforts in reflective network architectures discuss the utility of exposing implementation and state to network architects for improved network services.

Reflective cellular architectures offer a much broader view

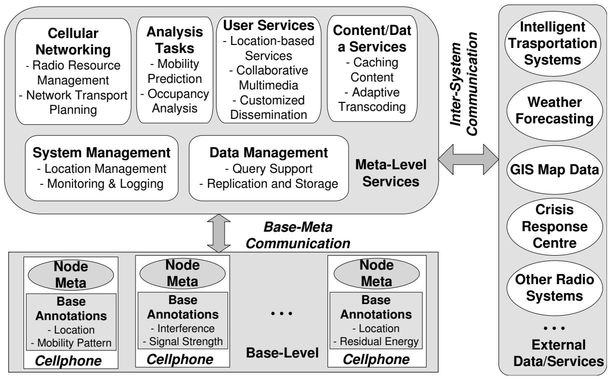



**Figure 2: Overview of a Reflective Cellular Architecture**

of the cellular technology, beyond its traditional role of accommodating user-centric devices. Rather than being simply conduits facilitating personal communication requirements, cellular technology can now be viewed as very large and pervasive networks of devices capable of capturing (sensing) and communicating a variety of information about the state of the network and the devices immersed in the network. In the resulting architecture, devices could gather, for instance, the state of the radio network, state of the protocol stacks, and nature of traffic and usage patterns at various locations. Raw information gathered can be spatiotemporally tagged, compacted and relayed over a possibly out of band communication channel to a repository where the data can reside persistently for others to utilize. This persistent repository, which could be distributed physically, can be organized as a single coherent entity (database) that can be queried over the cyber-infrastructure. Such a view offers numerous advantages both from the perspective of the end-user (with applications on handsets) as well as that of service providers (infra-structure and service deployment).

The architecture of a RCA system (See Figure 2) shows two well-defined levels: the functional level (also known as the base level) that executes the functionality of the cellular application (voice/data communication), and a meta-level that observes and potentially customizes the base-level communication. Realizing such a RCA system is not straightforward. Firstly, there is significant complexity associated with the *reification* process (i.e. the capture and observation of underlying base state). It requires the definition of a meta-level architecture that clearly scopes out the observable parameters (configuration data) and its use in the adaptation process (reconfiguration rules). Secondly, maintaining efficiency and performance of data transport in the presence of the additional modules for observation and adaptation is a significant challenge. Our recent efforts in the area of reflective messaging have developed techniques for customized delivery of messages to end-users; however, in our experience, performance optimizations require knowledge of the underlying context. Recent work in extensible router architectures have indicated that software based packet scheduling and forwarding is a viable approach for adapting communication, which is an encouraging sign. Thirdly, maintaining observable state in a scalable manner for dynamic data indicates that flexible data management must be a key component of this architecture. The adaptive data management technique for next generation cellular networks is a crucial challenge. Finally, assimilating the reflective architecture into existing cellular infrastructures in meaningful ways requires a good understanding of how cellular networks work. We believe that there are relatively simple ways to build a RCA on top of existing cellular infrastructures to enable reification/reflection; however, this requires a determination of the points at which the network must be instrumented.

In our RCA system, reification is supported through the use of base-level annotations, i.e. meta-data about base components. The annotations include the followings - location (if available), environmental sensing parameters, application level delays (for diffserv), signal strengths, residual energy levels, user mobility profiles (if predetermined) etc. Annotations associated with base objects that capture device specific characteristics are accessible by the meta-level runtime and meta-level services. If multiple meta-services use annotations, synchronization may be needed. The developed architecture will support advanced introspection of the annotations which may be used by the meta-services or trigger events when annotations fall outside the expected range.

## 3. FITTING EXISTING CELLULAR NETWORKS INTO RCA

Satisfying users' communication request with high quality has always been the main consideration when designing and planning cellular systems. However, there exist many factors that may affect users' satisfaction of cellular services. Examples of such factors include the limited amount of radio spectrum resource, the power/battery constraint of users' devices, the interference between active users, etc. The value and effect of these factors may vary in different network situations. Adaptively dealing with these factors can help cellular systems provide better services; several specific adaptation mechanisms have been independently studied without a larger view of the entire infrastructure. To illustrate how information collection and exchange plays an important role; we studied techniques for effective radio resource management in both GSM and CDMA networks that aim to provide enhanced network capacity under limited radio spectrum resource.

In the GSM system, a given radio spectrum is divided into a set of disjoint radio channels and these channels need to be reused in different non-interfering cells within the channel reuse distance. To satisfy a large number of user communication requests, channels need to be adaptively assigned to the call requests as they occur and terminate. Dynamic Channel Allocation has been drawing intensive research attention for over 30 years [10, 7]. The channel assignment process is triggered by a call request from MH. Upon receiving a call request, BS makes the decision of assigning a channel to the call for temporary use. The decision parameters are the channel usage of a cell, the number of call requests, cochannel interference ratio (CIR), signal strength to MH and etc. Based on the type of DCA schemas (centralized/cell-based decentralized/handset-based decentralized), the set of exchanged information between BS and MH is determined, but generally location information and channel information are exchanged.

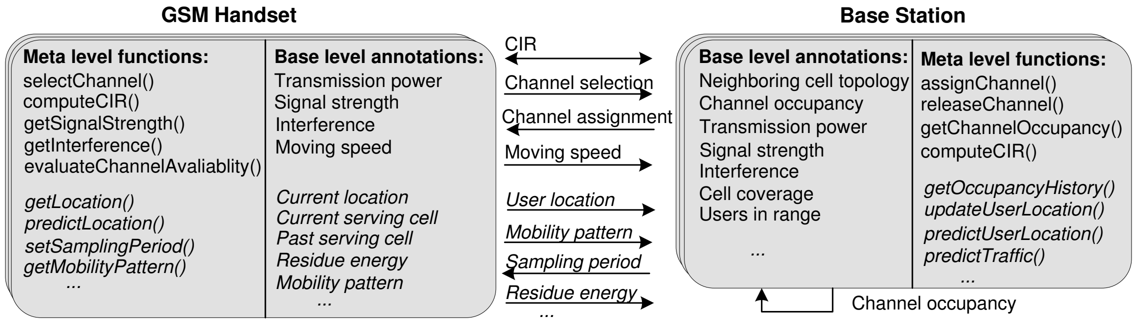
In a CDMA system, all the users share the available radio frequencies and use different orthogonal codes to send their signals. Thus signals to/from one user can be noise to other users; consequently, the signal strength and interference ratio should be balanced among the users. The major adaptation technique for CDMA networks is dynamic power control [9, 12], although some techniques also implement code adaptation [12]. Specific channel parameters need to be collected by BS's or MH's to optimize the transmission powers at MHs and BSs so as to accommodate a large number of users while ensuring acceptable noise levels. The operation of a CDMA network supports increased flexibility in call admissions as compared to the more rigid channel allocation techniques in GSM. Communication requests from users can be accommodated as long as noise levels are acceptable; however, it may trigger reconfiguration of transmission parameters of devices in the region. When the noise level reaches a threshold, the call is dropped. Most dynamic power control schemes are iteration based, in which the transmission power of BS's and MH's is periodically adjusted in the call duration. Thus, more dynamic interaction between MH's and BS's is needed.

RCA provides a well-structured platform for all the above adaptation techniques by guaranteeing the required information/data collection and exchange. Thus, the existing adaptations fit into the reflective architecture and can be enhanced for increased performance by the new view. Figure 3 shows how the information collection and exchange for GSM/CDMA handsets and base stations is supported on RCA.

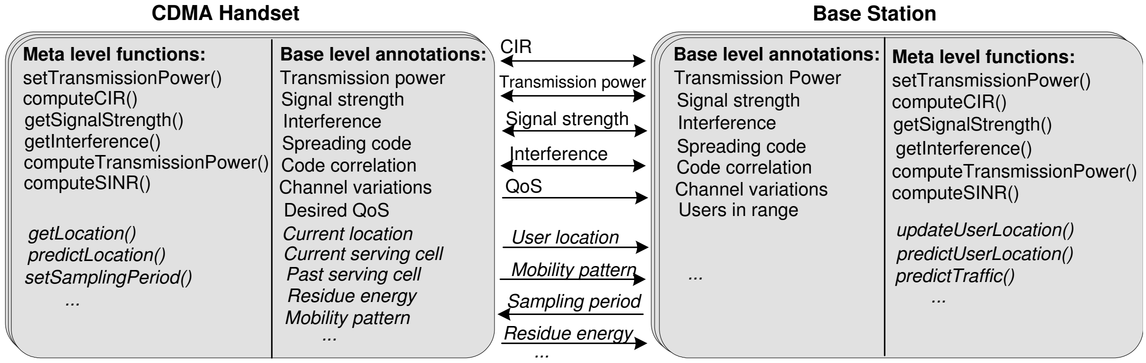
Some existing studies explore potential adaptation strategies which use resources outside existing cellular environments. For example, the dynamic spectrum allocation (DSA) scheme proposed in the OverDRiVE project [4, 6] tries to share the radio spectrum across different radio access networks (RANs) (e.g. cellular, WLAN, analog TV). It allows allocating only the amount of spectrum to a RAN that is required to satisfy the short-term traffic load with a certain user satisfaction level in a given area. Thus, spectrum utilization information and traffic conditions of different radio systems and their deployment are needed. Such out-of-band information resides outside the current cellar networks. RCA also enables intersystem information exchange, which provides the ability to deploy DSA schemas effectively.

In our existing work [17], we made a case for using reflection in radio resource management. We designed an adaptive algorithm - Prediction Based Channel Allocation algorithm (PBCA), which is a radio resource allocation algorithm which solves a key issue in GSM network, Dynamic Channel Allocation, using predicted location information. In the PBCA, BS of a cell is able to pro-actively allocate channel resource by estimating the channel request based on the predicted location information in order to reduce the ratio of dropping call request within hotspot cells. That is, if a BS predicts that it will need more channels than its own channel limit after a specific lookahead time, it pro-actively borrows available channels from neighboring cells before receiving surge of call requests. According to this, the PBCA can spread the load of surge of traffic among neighboring cells.

In the RCA, the role of the PBCA is adjusting the channel occupancy based on the predicted user location, the current channel occupancy and the current call dropping rate. The PBCA can be implemented as a meta-level service, such as the radio resource management module of the cellular net-




(a) GSM




(b) CDMA

**Figure 3: Information flow between handsets and base stations for GSM and CDMA**

working service in Figure 2. The PBCA meta-level service provides meta level functions such as *assignChannel()* and *releaseChannel()* to update the *channel occupancy*. The current channel occupancy and the call dropping rate, which are primitive base-level annotations, can be easily obtained by using *getChannelOccupancy()* meta-level function of the cellular networking service. However, to get the predicted user location information, we need another meta-level service supporting the location information management, which is the location management module of the system management meta-level service illustrated in Figure 2. The location management meta-level service observes and stores *user locations* and *mobility patterns* with the given *sampling period* (by using *updateUserLocation()* function), and provides the predicted information with *predictUserLocation()* and *predictTraffic()* meta-level functions.

The key input parameter of the PBCA is the predicted user location which is calculated based on the history of the sampled user locations. In the next section, we explore the various kinds of methods to predict user locations for a location information management meta-level service in the aspects of the correctness of the predicted information and the impacts of the misprediction to the other meta-level services including PBCA service and GeoAlert meta-level service (customized location based alerting service).

## 4. A BASIC META-LEVEL SERVICE : LOCATION INFORMATION MANAGEMENT

Collection and observation of base level data is a core aspect of any reflective system. This is illustrated in the RCA meta-model (Figure 2) where the system/data management module is a basic meta-level service. The granularity and frequency of observation and information interchange often dictate the quality of the captured data and consequently the efficacy of adaptations in a reflective framework. In this section, we address some issues in adaptive capture and management of the observed data. In a general sense, this involves capturing (or evaluating) the observable data at different levels of granularity (coarse and fine) and in different time domains (past, current and future). Using location related information of mobile hosts as a base-level observable parameter; we develop and evaluate techniques for predicting location information at different levels of granularity - using reified information already captured in the RCA. Our choice of location data is based on the fact that the deployment of cellular services and their quality is inherently dictated by the location of MH's and BS's. At a coarse level, we model location information as cell occupancy, i.e. number of hosts in a cell. Knowledge of current and future occupancy is useful in estimating the distribution of required network resources in each cell. At a fine grained level, we capture the accurate location information of individual hosts - this is useful for a variety of user oriented services.

There are two main categories of prediction methods: *estimation from the network view point* and *estimation based on individual behavior*. Estimation from the network view is usually based on statistical models and characterizations of spatiotemporally distributed traffic (e.g. highway vs. downtown models) [15]. The result of such estimation is typically used in an early phase of network design and planning using which actual deployment is carried out (e.g. allow the network to support relatively more cell phones in downtown than in rural areas). While the estimation from the network view predicts the longer term occupancy of a cell, the estimation based on individual behavior predicts the near future aggregate occupancy of a cell by collecting and processing individual users' location (supported by any localization techniques such as GPS) and trajectory information across regions [18, 14]. Since the purpose of RCA is supporting dynamic adaptation with continuous observation of base-level data, we need a meta-level service providing near future prediction of coarse/fine level location information rather than long-term prediction.

## 4.1 Coarse grained level information : Cell occupancy prediction

Cell occupancy is a coarse metric of location information in a cellular network. We propose two simple methods of occupancy prediction to estimate the number of devices in a given cell at a certain future time : *coarse non-individualized occupancy prediction (CNOP)* and *coarse individualized occupancy prediction (CIOP)*. In CNOP, each BS reports a time series of its occupancy over time, i.e., the number of cell phones connected to it in successive time sampling instants. Such a method may seem naive, but its performance should be considered before more elaborate techniques are devised. Intuitively, if prediction is short-term, the occupancy of each cell is expected to change by only a small amount, due to inertia of mobile hosts: it is fairly improbable that the stochastic entry/exit of hosts into the cell will disturb the aggregate number of hosts by a significant amount. On the other hand, in CIOP, each BS gathers the information of individual users such as which users are currently in its range, when they entered the current cell, which neighboring cell they are from and how long they stayed in the previous serving cell. Assume the users will spend the same amount of time $t$ in the current cell as they spent in the previous serving cell. We further associate specific probabilities to the neighboring cells to indicate the likelihood that the user may enter that cell, and calculate the aggregate occupancy prediction within $2t$ ($t$ in the current cell and $t$ in the next cell). Note that different probabilities can be applied to different geographic conditions and under different user mobility patterns.

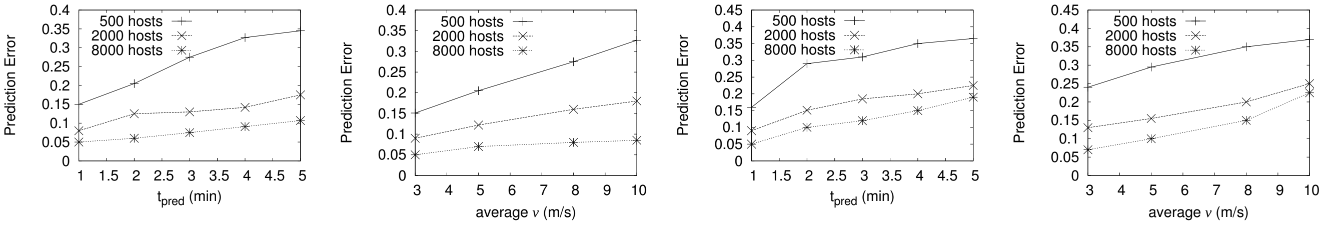
To evaluate the two methods, we simulated mobile hosts on an 11x11 grid of cells, each of which has an internal diameter of 2000m. Cell phones are initially placed randomly in space (uniformly), choose a random destination point in the space as the destination, and a random velocity from interval $[v_{min}, v_{max}]$ and proceed to the destination with that speed; the process is then repeated (after arrival at the destination) until the simulation time is over. We have simulated this process varying the number of cell phones in the entire space ranging in 500, 2000, 8000, average velocity $v_{min}$ from 3, 5, 8, 10 with $v_{max} = v_{min} + 4$ (in m/s). Simulation time was 60min, with occupancy samples obtained every 1min for the ground truth. We assessed the efficacy of our technique by varying the lookahead time $t_{pred}$, defined as the number of minutes in advance that prediction is required. We plot the *occupancy prediction error* defined as the average absolute occupancy error divided by the average cell occupancy. For example, if average absolute occupancy error is 8 (cell phones), and there are in total 8000 cell phones, the prediction error is $8/(8000/121) = 0.121$.

The results plot prediction error against the lookahead time and against the average speed (defined as $(v_{min} + v_{max})/2$). Results are shown in Figure 4. The main conclusion from these results is that even the simple method, CNOP, suffices to provide reasonably accurate occupancy prediction in the short term. Basically, the accuracy of occupancy prediction decreases as both of the lookahead time and the speed of cell phones increase. But, as the load on the system (measured by the number of cell phones) increases, the accuracy of our methods increases. Intuitively, with few cell phones, a small number of cell phones moving across cell boundaries has a substantial effect on prediction error, but this becomes less important as cells become crowded with cell phones.

## 4.2 Fine grained level information : Individualized location prediction

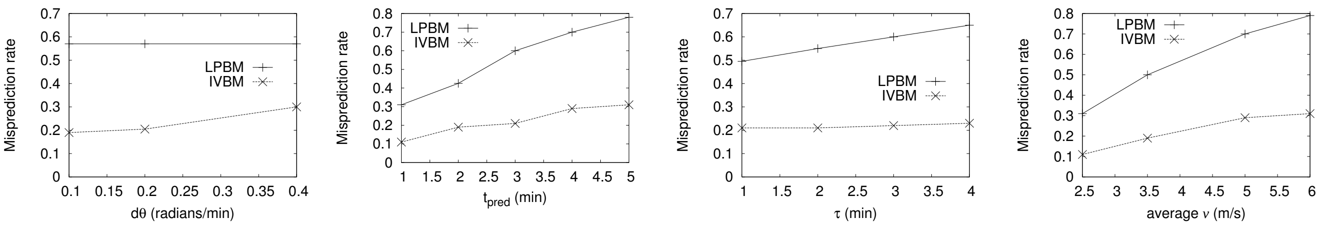
Individualized location is a fine metric of location information which is useful for a variety of applications that can not rely on the coarse location information and desire to control more customized services. For instance, resource reservation is important for the cellular system to provide consistent services with quality guarantees. In order to enable such reservations while optimally utilizing system resource, it is imperative that the location of individual cell phones is known precisely (and in advance), so that resources are reserved and released promptly, in tandem with the cell phones motion across different cells. For the purposes of near-term prediction of individualized location of a cell phone, inertial prediction may suffice, which assumes that objects will maintain their current velocity vector into the near future. It can be easily seen that this model approximates many types of ordinary human behavior, such as sitting, walking or driving purposefully. In this motion model, each cell phone may capture its own location (e.g., using assisted GPS) periodically, estimate its speed, and transmit a vector of parameters $(x_0,\ y_0,\ v_x,\ v_y)$ to the appropriate cellular network location monitoring service, which can then extrapolate the cell phone's location into the future. We have implemented a version of this *Inertial Vector Based Method* (*IVBM*), which estimates the velocity vector from the last two location fixes, and can be parameterized to sample location at a given period $t$. We have also implemented a simpler model which estimates a cell phone's location as its last known location; in this model, only $(x_0,\ y_0)$ needs to be transmitted. This *Last Position Based Model* (*LPBM*) is conceptually simpler, and is expected to perform reasonably well for near-term prediction, since objects cannot move by a great amount in a short period of time; LPBM is also expected to perform well for slow moving objects (corresponding to e.g., office workers, or pedestrian shoppers).

As per our discussion above, we are sometimes interested in predicting individual location to facilitate individualized resource reservation. The time series of predicted location can be used to reserve/release resources in advance for the user's applications in different cells. Thus, a measure of the quality of prediction can be defined as the fraction of wrong predictions over all predictions, i.e., the times that the cell phone is estimated to be in the wrong cell (leading to wasted resources in that cell, and missing resources in the cell where the cell phone actually is located). We call this, the *location misprediction rate*. In our experiments,




(a) CNOP:Lookahead Time (b) CNOP:Host speed (c) CIOP:Lookahead Time (d) CIOP:Host speed

**Figure 4: Performance of occupancy prediction methods (CNOP and CIOP).**




(a) Direction Volatility (b) Lookahead Time (c) Sampling Frequency (d) Host Speed

**Figure 5: Performance of individualized location prediction methods (IVBM and LPBM).**

we have maintained the same settings for cellular network layout, cell size as the setting of the evaluation of occupancy prediction. We fix the number of users to be 2000. We varied object velocity as before, but rather than using an origin-destination model with constant speed (which would be ideal for motion prediction), we allowed objects to change their velocity at each simulation step by a small amount (uniformly chosen between $-v_{min}/5$ to $+v_{min}/5$), as well as their direction of motion by a small angle (between $-d\theta$ and $+d\theta$). We varied $d\theta$ between $\pi/32$, $\pi/16$, $\pi/8$. We have also varied the sampling period $\tau$ in 1, 2, 3, 4 min. The number of messages and localization samples is inversely proportional to $\tau$. Results are averaged over all choices for the parameter which is not plotted, e.g., lookahead time $t_{pred}$, $d\theta$ and $v_{min}$ in the error vs. $\tau$ plot. Finally, we added uniform error of U[0,50] m to the location fixed provided by the individual localization service (e.g., GPS).

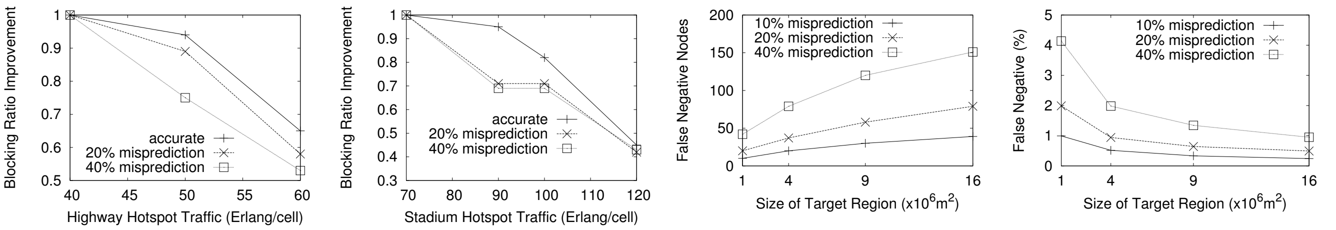
The results are plotted in Figure 5; each plot shows the cell misprediction rate against the free parameter. As expected, this rate increases as motion volatility increases (Figure 5(a)), as prediction lookahead time increases (Figure 5(b)), as samples are obtained less frequently (Figure 5(c)), and as the average speed of cell phones increases (Figure 5(d)). Moreover, in all cases, the smarter method, IVBM, outperforms the simpler method, LPBM. The efficacy of this solution could be further enhanced, e.g., by taking into account road network structure which would supply information for directional motion changes that cannot be captured by a uniform motion model. But, nonetheless, our results indicate that even a simple predictive model based on constant motion is capable of localizing mobile hosts within cells to a substantial degree.

## 4.3 Utilizing the location prediction meta-level service

The prediction of coarse/fine-grained level location information can be illustrated as a meta-level service such as analysis tasks module in Figure 2, and other meta-level services (e.g. radio resource allocation, customized dissemination) can use this predicted location information by using meta-level functions such as *predictUserLocation()* or *predictLocation()* in Figure 3. These meta-level services rely on the predicted location information provided by the location management meta-level service, and the misprediction of location information may affect their performance significantly. We evaluate the impact of misprediction of location information to two meta-level services : the radio resource allocation service and customized dissemination service.

**Radio Resource Allocation :** In the PBCA, Misprediction of location information causes that a BS allocates over or under estimated channel resource, and the performance of PBCA may decreases. We evaluated the performance degradation through ns2-based simulations for cellular networks with 350 channels in a cell. The detailed settings are found in the paper [17]. Figure 6(a) and 6(b) show the impact of misprediction in terms of performance improvement of PBCA over LP-DDCA (one of distributed DCA schemes) in a highway scenario and a stadium scenario. Basically, PBCA achieves better performance in a stadium scenario, where a hotspot cell has more non-hotspot neighboring cells, than in a highway scenario. According to this, the impact of the misprediction to a stadium scenario becomes significant, and PBCA for the stadium scenario requires more accurate predicted location information which may cause the cost of collection and maintenance of individualized location information. On the other hand, PBCA in a highway scenario is more tolerant against the low/mid level of misprediction, and the coarse grained prediction of location information is enough to support the highway scenario.

**Customized Dissemination :** The predicted location




(a) Impact to PBCA-Highway (b) Impact to PBCA-Stadium (c) Impact to GeoAlert:# of false negative (d) Impact to GeoAlert:% of false negative

**Figure 6: Impact of misprediction of location information to other meta-level services.**

information can be applied to implement and customize spatiotemporal services. Dissemination information, especially during a crisis situation, may be dependent on user locations, which may dictate the urgency or the content [8]. GeoAlert, a customized spatiotemporal service, is a regional multicasting service to inform a message to all of the recipients who locate inside a given geographical region (e.g. send accurate evacuation paths to users in a specific region affected by a crisis urgently). GeoAlert filters the target recipients of a regional multicasting message based on the predicted location information. The predicted location information is important for GeoAlert in order to reach the users possible affected by the event in near future.

With misprediction of location information, GeoAlert suffers from false negatives. False negatives means the case that a node, locating inside of the given target region of a message, does not get the message. These false negatives should be minimized. We simulated GeoAlert with 10000 recipients which are uniformly distributed over a 10000m by 10000m global target region. We assume that GeoAlert guarantees that a regional multicasting works correctly based on the predicted location information. The size of a target region of a message is smaller than the size of the global target region. In Figure 6(c), the number of false negative nodes increases logarithmically as the target region increases. However, since the number of target recipients is proportional to the size of the target region, the ratio of false negative decreases exponentially as the size of target region increases like Figure 6(d). According to this, we note that more accurate prediction of location information is required in order to support more fine-granularity of customized information dissemination reliably.

# 5. CONCLUDING REMARKS

Developing protocols for extended services such as reliable messaging, timely and secure communication in an RCA will require support for extended compositionality. The use of reflective architectures in designing various communication networks has been proposed in recent works [13, 5]. While this paper presents a reflective framework for a specific network (i.e. cellular network), our eventual goal is to develop a reflective multi-network architecture that will enable seamless exchange of information across multiple access networks. For instance, the cellular system can be combined with other network such as adhoc network to support users' desired quality of services [3] in order to support various kinds of users' QoS efficiently and effectively.

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