

Mobility Prediction for Seamless Mobility in Wireless Networks

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Abstract

One of the requirements for seamless mobility is efficient resource reservation and context transfer procedures during handoff. If context transfer and resource reservation can occur prior to handoff continuation of the same level of service as at the previous connection point is possible. Resource reservation is required to be non-aggressive for optimal use of limited bandwidth and a low call-blocking probability. In this work we present a method of mobility prediction that can aid in achieving seamless mobility. In order to optimise the efficiency of a resource reservation algorithm we believe accurate prediction of the future movements of the user is required.

Keywords

Mobility prediction, seamless mobility, resource reservation, handover, wireless networks.

1. Introduction

The vision of Next Generation Networks (4G and beyond) is to offer real-time multimedia services such as high-performance wireless teleconferencing, video conferencing and full-motion video by supporting high-speed transport. While 3G networks are based primarily on the wide area cell-based concept, 4G networks will essentially be hybrid networks that make use of cell or base station based wide area network design along with ad hoc networking and hot-spot (wireless LAN) concepts. In order for a prediction scheme deployed in existing 3G networks to smoothly transition to future 4G technology it needs to be efficient in both infrastructure supported and infrastructure-less environments. The prediction algorithm should not be sensitive to randomness in user movement patterns, as 4G networks are required to support global mobility. 4G networks are also envisioned as networks offering seamless and heterogeneous mobility which requires a potential 4G mobility prediction scheme to be non-technology specific.

Seamless mobility requires continuous resource reservation and efficient context transfer as the user moves from one location in the network to another. Resource reservation and context transfer to the new connection point should occur prior to handover to enable the user to receive the data or services at the new location, at the same level of service as at the previous connection point. While it is possible to aggressively reserve resources at all possible locations of the user on the network, this leads to an overall wastage of bandwidth resulting in unnecessary blocking of new calls. In order to optimise the efficiency of a resource reservation algorithm an accurate prediction of the future movements of the user is required. Hence there arises a need for highly accurate mobility prediction techniques. The mobility prediction algorithm needs only to identify the next connection point of the mobile user with respect to the network [Chan et al., 1998]. There is therefore, not a need to predict continually the geographical position of the user.

In this work we introduce the sectorized mobility prediction algorithm which, (a) can be employed to minimise the number of base stations/access points required for resource reservation, (b) achieves accuracy in prediction without introducing additional complexity in the prediction algorithm or in the network structure, (c) is efficient for both the regular and the random movements of the user and, (d) has the potential to be extended to an ad hoc networking environment and performs efficiently for all types of users i.e., low-speed, medium-speed, high-speed and aircraft or military users. Our simulation results prove that accuracy in prediction can be achieved with a considerable decrease in the total tracking area of the network.

In this work we focus our discussion on the deployment of the proposed scheme in a cellular wireless network. Section II gives an overview of related work. Section III introduces the sectorized cell structure and the sectorized mobility history base (SMHB). Section IV discusses the cell-sector numbering scheme that is used for random movements of users with the conclusions in Section V.

2. Related work

Most mobility prediction schemes proposed for cellular networks make use of a history base that has a record of the previous movements of users. These algorithms make use of the history base and by taking into account the respective probability of movements together with factors such as the direction of motion and the user's velocity; regular movements of users can be predicted fairly accurately. However with the introduction of even the smallest degree of random variation, traditional algorithms that predict based on the location criterion, direction criterion, segment criterion, time criterion or Baye's rule fail [Chan et al., 1998]. Their failure is attributed to an inability to adapt efficiently to the changes in user behaviour. The Mobile Motion Prediction (MMP) algorithm [Liu and Maguire, 1996] and The Regular Path Recognition Method [Erbas *et al.*, 2001] attempt to exploit regularity in human behaviour in terms of periodic or repetitive activities. Although the performance of these algorithms is accurate with regular movement patterns, accurate prediction of random movements is not addressed. The Shadow cluster concept [Levine *et al.*, 1997] makes use of the user's movement history to create a shadow of the user's future positions and advocates probabilistically reserving resources along the possible path. The drawback is that resource reservation can be overly aggressive causing an increased blocking of new calls. The Hierarchical Position Prediction (HPP) Algorithm [Liu *et al.*, 1998] makes use of the user's history of movements in addition to the instantaneous RSSI measurements of surrounding cells. While agreeing that the inter-cell mobility of the mobile user is governed directly by the movement pattern of the user within the current cell we argue that the tracking of the user need not be performed in the complete cell area. The HPP algorithm remains reasonably accurate (75%) despite the influence of random movements. The Profile based Next-Cell Prediction algorithm [Bhargavan and Jayanth 1997] is based on location classification and user movement history. Prediction is found to be 80% accurate for regular movements and 70% accurate for random movements. However movements are restricted to indoor locations such as an office, corridor or common room. The user movement tendency prediction algorithm [Ciu and Shen, 2000] characterizes each user by making a judgement as to whether the user is moving or not. The required inputs are user's location and velocity estimation records, local geographical features and statistical traffic information. The algorithm also works on the assumption that the traffic speed distribution and the speed of the user is a

constant along each road. The Neural-Network Based Prediction Algorithm [Poon and Chan, 2000] proposes a hierarchical scheme that takes into account both global and user level information while performing the prediction. The type of method proposed however requires the design of a neural network as well as prior detailed geographical knowledge of the cellular structure

3. The Sectorized Mobility Prediction algorithm

The proposed scheme is built on the rationale that in order to achieve maximum accuracy in movement prediction the prediction process should be restricted to areas of high handoff probability. To ensure prediction accuracy the process must guard against under-prediction (i.e., commencing the prediction process too late so as to miss a handoff) and over-prediction (i.e., predict too early along a user path). Prediction restricted to the last few movement legs of a mobile user ensures higher accuracy of prediction. To this end we introduce the sectorized cell structure to aid in mobility prediction. The sectorized mobility prediction scheme introduces the sectorized cell structure along with the sectorized mobility history base to aid in regular user movement prediction and makes use of the cell-sector numbering scheme to predict the random user movements. We define moving along a previously stored pattern as a regular path and following a new user path as a random path).

3.1 The Sectorized Cell Structure

If we assume a hexagonal cell structure as shown in Fig.1 (a), there is a region of the cell wherein the probability of handoff is negligible (even zero) – which we define as the No-HO region. The argument is that a user in this region of the cell cannot receive beacons of sufficient signal strengths that satisfy the threshold for handoff from any of the neighbouring cells. As a result it would seem reasonable to suggest that a handoff is not possible and/or desirable. Hence users belonging to this category will not be considered for prior allocation. There is a region in the middle of the cell where the probability of handoff is low – which we define as the Low-HO region. This is because the quality of connection offered to the user in this region of the cell is still sufficient and hence the probability of the user executing a handoff from this region of the cell is fairly low. There is also a region in every cell where the probability of handoff is fairly high - which we define as the High-HO region. This is the region of the cell where the mobile user is able to receive beacons from neighbouring cells that are above the threshold required for handoff. However, it is to be noted that the decision for handoff is not dependent on only the relative signal strength (RSS) measurements. For a successful handoff a goodness function is to be satisfied which would take into account available resources on the contending cells. The RSS value would be weighted into the goodness function.

Based on the above observations, we suggest a novel method of cell division that makes possible accurate mobility prediction with sufficient reduction in required area of tracking. The cell is divided into three regions with respect to HO probability as No-HO, Low-HO and High-HO regions. It suffices to do this based on RSS values. The width of the regions could possibly be user specific, meaning highly mobile users can have a smaller Low-HO region and a wider High-HO region or network specific. The width of the No-HO region would not change, as it is dependant on the BTS and not related to the mobility of the user. User specific division is preferred in highly built locations to account for the variations in RSS values. The

cell is further divided into sectors and numbered as shown in Fig.1 (b). Each sector is adjacent to only one neighbouring cell and for all practical purposes it is assumed that it is only to this cell that the user would eventually handoff to.

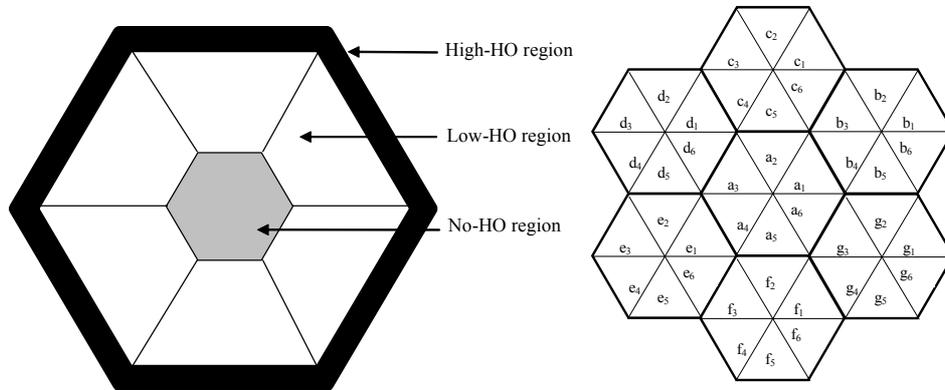


Fig.1 (a) Cell Structure based on handover probability (b) Sectorized cell structure.

3.2 The Sectorized Mobility History Base (SMHB) for user movement pattern matching

The algorithm does follow traditional methods in that we make use of previously recorded mobility patterns of the user to predict future movements. We follow the principle that the mobility of a user is a combination of regular and random movement patterns. Traditional algorithms store the past movements of the user from one cell to another on a cell-by-cell basis in a mobility history base (MHB) as shown in Fig.3. Depending on the current cell of the user and successful identification of the user specific mobility track the most likely subsequent cell is predicted. The drawback of these algorithms is that the accuracy is directly related to the length of the mobility track i.e., if the user is in the middle of a recorded mobility track after having followed it accurately for its x previous movements then the probability of it continuing with the same path for its $(x+1)^{th}$ movement is sufficiently high than if otherwise.

We propose the use of the sectorized mobility history base (SMHB) as shown in Fig.4, which stores the positions of the user on a sector-by-sector basis rather than cell-by-cell. As we track the sectorized movements of the user we can identify HO points as the user moves from one cell to another cell. The proposed method of maintaining user movement history might result in an utmost six-fold increase in the length of the stored pattern but the increased accuracy of prediction is bound to compensate for this overhead. This six-fold increase however is the worst-case scenario, where the user insists on moving in a circular pattern within each of its cells of residence, which is a rare movement pattern. The advantage of the sector-by-sector tracking method is that it will be efficient even in cases where the mobile user has not sufficiently progressed (in terms of cell handoffs) along a previously recorded mobility track. If we record the past movements cell by cell then the number of possible handover points from each cell assuming a hexagonal cell structure is 6. Whereas in the case of sector-by-sector recording the number of possible handover points can be brought down to 1 (the cell with which the current sector shares an edge with) or at the very least to 3 (the cell with the common edge and the 2 cells that share vertices with the current sector), which still is a two-fold decrease in the sample space. This decrease in the number of possible handover points contained in the sample space results in an increase in the probability of an accurate

prediction. To increase the accuracy of prediction for users who haven't sufficiently progressed along a recorded mobility path we treat them as users in a random walk mode as explained in section IV.

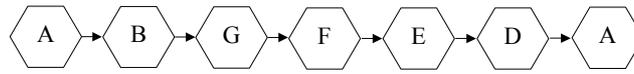


Fig.3 Mobility history base

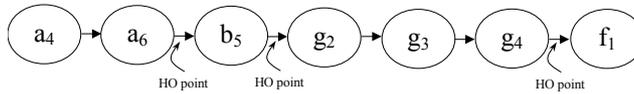
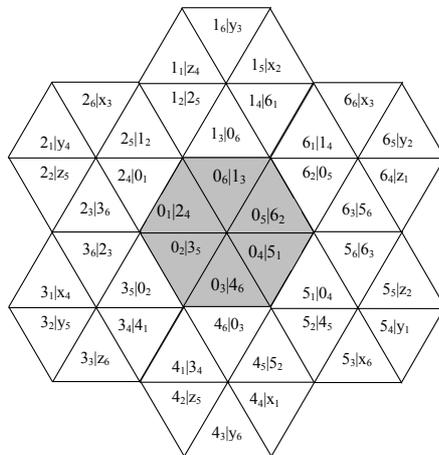


Fig.4 Sectorized mobility history base (SMHB)

4. The Cell-Sector numbering scheme for random user movement prediction

While the regular movements of the user are predicted using a SMHB once it has been identified that the user is on a random movement track (i.e. on a previously not encountered mobility pattern in the network) - a method of prediction of the random movements of the user is required. While it is possible to obtain accurate tracking by making the prediction process highly complex the proposed method is computation non-intensive and introduces minimal amounts of additional traffic on the wireless link. We introduce the use of a cell-sector numbering scheme that can predict the next handover point. The proposed numbering scheme is as in Fig.5.



Definition :

Each sector of cell 0 takes a value $0_i | a_j$
 where $i = 1 \dots 6; a = 1 \dots 6; j = 1 \dots 6$
 further $a = (i + 1) \bmod 6$ & $j = (i + 3) \bmod 6$
 And a neighbouring sector takes a value $a_j | 0_i$

Fig.5 The Cell Sector numbering scheme

The scheme sits on top of any other cell-numbering scheme and is only for the purpose of mobility prediction. As shown in the Fig.5, the cell that the user is resident in (greyed) is always identified as the reference cell 0, i.e., if the user moves from cell 0 in the figure to cell 5 then cell 5 is referred as cell 0 for mobility prediction purposes. Each sector of the resident cell is then identified using $0_i | a_j$ where '0' is the reference cell and 'a' denotes the neighbouring cell to which the user can handoff to from this particular sector of the reference cell. Re-referencing of a neighbour cell is only done if the distance from the original reference cell sector to the present resident sector is at the least 2 cell-sector crossings. The system is

robust enough to handle oscillating users between two sectors of different cells without any re-referencing.

5. Simulation Study of the Sectorized Mobility Prediction scheme

Performance study of the proposed sectorized mobility prediction scheme in a cellular environment was done making use of the OPNET modeler 9.0 simulation tool. OPNET provides a comprehensive development environment supporting the modelling of communication networks and distributed systems. Both behaviour and performance of the modelled system can be analysed by performing discrete event simulation.

The focus of the simulation study was to evaluate to performance of the algorithm with respect to its extensibility to next generation networks. The scheme would need to exhibit compliance to foundational protocol principles for both hybrid and completely ad hoc network environments. With this focus our points/metrics of interest were: -

- **Prediction Accuracy:** The ratio of the number of handoffs actually executed by the user to the number of handoffs predicted by the scheme. To be incorporated successfully into a resource reservation scheme the prediction process should guard against over-prediction.

$$\text{Prediction Accuracy} = \frac{\text{No. of user handoffs} - \text{No. of prediction misses}}{\text{No. of user handoffs} + \text{No. of over predictions}}$$

- **Randomness Factor (R_f):** The ratio of handoffs executed by the user that were not in the SMHB to the total number of handoffs executed by the user. The scheme should be able to adapt to high degrees of randomness in user movement without compromising the prediction accuracy.

$$\text{Randomness Factor } (R_f) = \frac{\text{Number of user executed handoffs not in SMHB}}{\text{Total number of user executed handoffs}}$$

- **Ratio of control overhead:** The ratio of the control traffic introduced into the wireless link by the prediction process to the total data traffic on the wireless link.

$$\text{Ratio of Control overhead} = \frac{\text{Amount of prediction related control traffic}}{\text{Total amount of data traffic}}$$

- **User Mobility Support:** The scheme should be able to support different user types with comparable levels of prediction accuracy and control overhead.

The simulation model consisted of a cluster of hexagonal cells. The base station for each cell resides in the centre of the cell. In order to maintain consistency of results and ensure that all cells have equal handoff probabilities user executed handoffs from outlying cells are not included in the simulation results. To maximize the number of handoffs executed on the network each mobile user was assumed to maintain a call for the entire simulation interval. The movement of the mobile user was not restricted in relation to direction or step size. The simulation environment allowed users to move in any arbitrary direction (between 0 & 2π) and vary their speed at random intervals. Depending on the user category there exists [MinSpeed, MaxSpeed]. Simulation runs were conducted for pedestrian or low-speed users with a speed of 4 km/hr - 6 km/hr, medium-speed users with a speed of 15 km/hr - 55 km/hr

and, high-speed users of speed 100 km/hr - 130 km/hr. The diameter of each cell was set approximately to 1000 meters. Simulation runs were conducted with different random seeds and the results were averaged over all these iterations.

5.1 Simulation Results

Fig.6 shows the Prediction accuracy Vs. Tracking Area results for all three types of users with a randomness factor of $R_f = 0.6$ and $R_f=1$. $R_f = 0.6$ implies that 40% of all handoffs have been recorded in the SMHB and only the remaining 60% are to be predicted by making use of the cell-sector numbering scheme for random user movement prediction. The prediction accuracy is thus 40% even when the High-HO region is zero. It is observed that there exists a critical value of the High-HO region for which the prediction accuracy is maximum (100%). For a randomness factor of 0.6, perfect prediction accuracy is achieved for all three types of users. However this is dependant on the size of the High-HO region (size of the tracking area). It is observed that the size of the tracking region is increasing as the speed of the user increases. As users of lower speeds tend to make more number of movements in the High-HO region the area of tracking has to be reduced to enable prediction as late as possible. Fast moving users on the other hand have to be tracked for a minimum time before a prediction can be made and this requires a larger tracking region than a slower moving user. As the tracking area is increased beyond the critical size the accuracy of prediction is found to decrease. There is inaccuracy introduced in the system as a result of over-prediction occurring once the tracking area increases beyond the maximum accuracy level. $R_f = 1$ implies that the scheme is required to function independent of the SMHB as there are no recorded user movement patterns. It is observed that the scheme is capable of accurate prediction in the completely random movements scenario with critical areas of tracking being 40%, 47% and 54% of the cell area for the slow moving, medium-speed and high-speed user respectively. The scheme by offering maximum accuracy independent of the SMHB exhibits potential to be extended to the ad hoc networking domain, as user movement patterns are not possible to be maintained in a dynamic network structure. Also the reduction in the area of tracking augurs well for the scheme in comparison to traditional schemes that require tracking in the complete cell area.

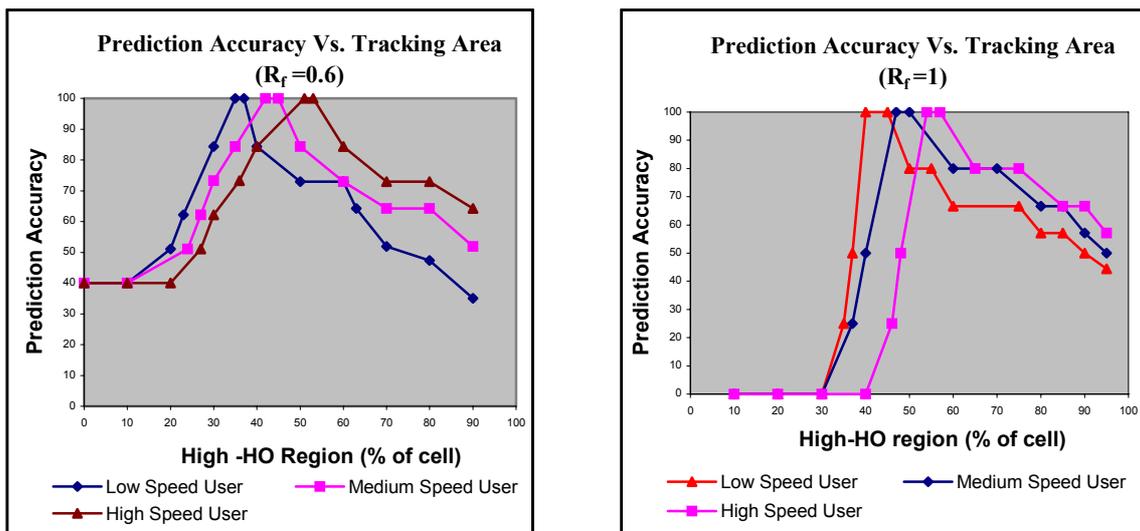


Fig.6 Prediction Accuracy Vs. Tracking Area

Fig.7 reports results for Randomness Factor Vs. Tracking Area (100% accuracy). It can be seen that there is a definite but marginal increase in the critical area of tracking as the randomness factor increases. Fig.7 also reports the performance of the sectorized mobility prediction scheme in comparison to other mobility prediction schemes in terms of robustness to randomness in user movements. We have considered the MMP, MLC and the MLPS algorithms for our comparisons. MMP and MLC both make use of constitutional constraints to increase the accuracy of prediction. We have compared our results with the MMP (0%) and MLC (0%) scenario when no constitutional constraints are in place and the MMP (92%) and MLC (91%) scenario when maximum constitutional constraints are in place. It is observed that the performance of the sectorized scheme is superior to the other schemes. The prediction accuracy of the other schemes is found to almost linearly decrease with increase of randomness in user movement. The accuracy of the sectorized scheme, even in the case when there is a 20% error introduced in the specification of the Hi-HO region is still considerably higher than the other schemes. The decrease in accuracy is partly attributed to over prediction in which case all handoffs executed by the user are still predicted accurately.

Fig.8 reports on Tracking region Vs. Control overhead for the three different user speeds. It can be seen that the control overhead introduced by the prediction mechanism is found to increase as the area of tracking is increased. The dotted lines in the plot indicate the maximum accuracy or critical size of the High-HO region for the different user speeds and their corresponding control overhead. As expected the control overhead is proportional to the user speed. The slowest moving user introduces the lowest amount of control traffic and the highest speed user the most. The observed results indicate that the control overhead for a low speed and medium speed user is around 3% while for a high-speed user (100-130 Km/hr) the control overhead for maximum accuracy is around 4.3%. The scheme introduces minimal amounts of control traffic even for tracking in the complete cell area. A user requiring tracking in complete cell area because of its speed of travel would still introduce less than 10% of control overhead in the network. The scheme is thus especially suitable for resource intensive data networks supporting high-speed user mobility.

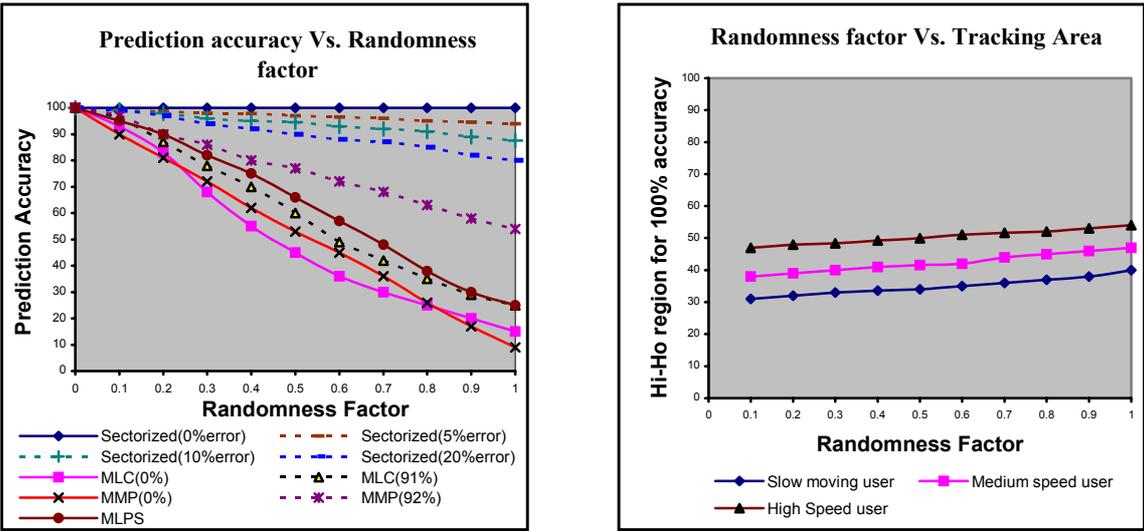


Fig.7 Study of Randomness factor

6. Conclusion

In this work we have introduced the sectorized mobility prediction algorithm making use of the SMHB for regular user movement prediction and the cell-sector numbering scheme for random user movements. Simulation study of the proposed scheme was conducted using OPNET modeler 9.0 with focus on the potential of the scheme for extensibility into the ad hoc networking environment. Simulation test results were observed for prediction accuracy, robustness of the scheme to randomness in user movement and control overhead introduced by the prediction scheme. It is seen that the scheme is capable of high levels of accuracy despite randomness in user movement patterns and introduces minimal amounts of control overhead on the wireless link.

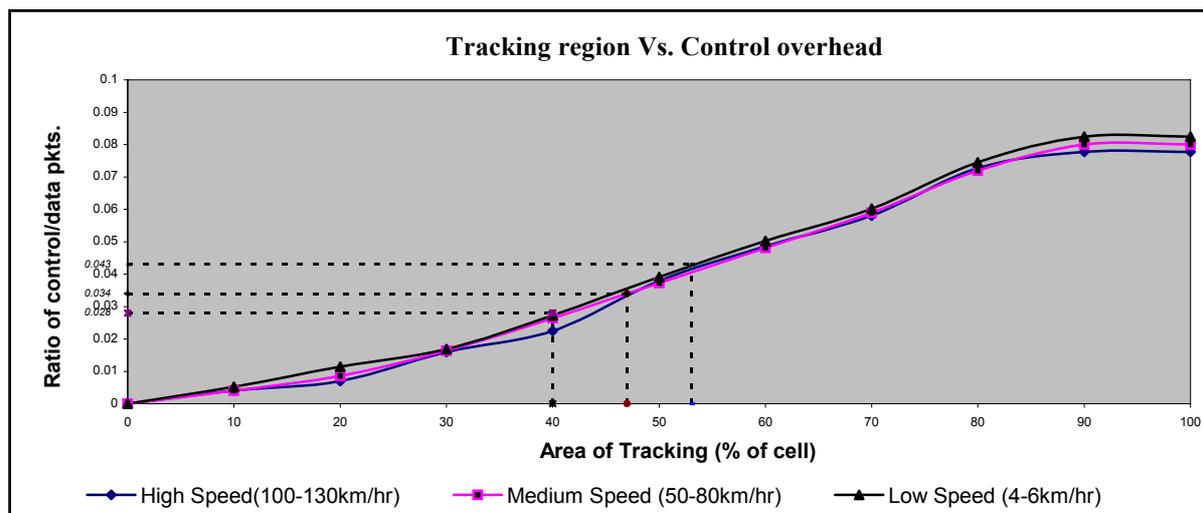


Fig. 8 Tracking Region Vs. Control Overhead

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