Improvement of Handoff in Wireless Networks using Mobility Prediction and Multicasting Techniques

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Abstract:- Achieving seamless mobility is a significant challenge for wireless networking today. This paper illustrates the use of multicasting techniques aided by mobility prediction to improve handoff performance in wireless networks. Handoff holds the key to defining the performance of wireless networks since there could be packet losses during handoff as the mobile node moves from one point of attachment to another. A new method of determining a multicast tree routing scheme with specific performance objectives is presented in this paper. The Grey model has been used as the prediction methodology as it has been shown to provide good prediction accuracy[1]. A situation is modelled where a multicast tree is defined covering multiple access routers (AR) to maintain connectivity with the mobile node using mobility prediction (by selecting the least number of access routers) whilst ensuring guarantees of bandwidth and minimum hop count such that packet loss can be avoided. To simultaneously solve the above two problem formulations gives rise to a multi-objective optimisation problem. Discovering the optimal routing is an NP hard problem where network state information is not accurate, which is a common feature in wireless networks. After describing the problem, an algorithm that satisfies the constraints and objectives with a near optimal cost is presented.

Key-words:- Handoff, Handover, Grey Model, Multicasting, Spanning tree algorithm, Shortest path algorithm.

1 Introduction

Good mobility prediction [1][2] holds the key to improving performance when calls are being handed-off between cells. Handoff is the call handling mechanism invoked when a mobile node moves from one cell to another. When a handoff is being performed, there can potentially be a loss of packets [3]. In order to improve handoff performance, a promising technique is to perform mobility prediction [4]. Mobility prediction is used to highlight the minimum number of access routers required to build a multicast tree with members who are the routers for the mobile node. An important methodology that supports this prediction is known as Grey theory. This theory is useful and has been widely applied in weather predictions and control system applications, as it needs only a limited amount of data for the construction of the model. As little as four measurements of the signal strength are required to enable a prediction to be made. As the process needs only minimal data, it provides fast computation times and good prediction accuracy [2]. One approach discussed in this paper is the use of a Grey to select the minimum number of AR's needed to build an optimal multicast tree.

Multicasting is an efficient means of group communication. It has been used for video-conferencing and many other realtime applications, the advantage being bandwidth savings. Routing packets from the source to the destination in an optimal way not only decreases end-to-end delay but it also saves on network resources. These factors also influence handoff performance in terms of handover delay and packet loss. There are many protocols that have been proposed to overcome these performance limitations in the literature. Methods for alleviating these problems have been described in several studies [5].

In M&M [6], the authors try to improve handoff performance by proposing a CAR (Candidate Access Router) approach. As a mobile node moves from one coverage area to the next, the candidate access routers are selected in such a way that there are no losses. Doing so leads to multicast overheads in terms of bandwidth usage and delay as it uses more network resources. The Internet Engineering Task force [IETF] group has proposed the protocol known as Mobile IP [7]. Mobile IP has two services for mobile hosts depending on whether it uses a home network or a foreign network [8]. A mobile receiver will experience delay in receiving multicast packets when it moves into the network with no group members. Frequent modifications of the multicast tree incur a significant routing overhead since an existing multicast tree cannot be changed easily or efficiently. These multicast tree structures are very unstable and require adjustments as the connectivity changes every time that there is a handoff. It has been noted that the some key factors that influence the structure of the multicast tree are frequent changes in topology, transmission of control packets, packet losses, limited bandwidth power and mobility [9][10].

These issues along with low bandwidth and higher bit error rates in wireless networks make efficient IP multicast a challenging task in a mobile environment. An approach to IP mobility using standard multicasting has also been proposed in the literature [9][11]. In this approach, the mobile node is assigned a multicast address through which it joins the access routers that it visits during its movement. Handover is performed by standard IP-multicast join and prune mechanisms [12]. Further, dynamic algorithms can be designed to identify probable new access routers [AR]. If there is replication of packets, there should be a heuristic, that will reduce this overhead. When the old AR sees that the signal from a mobile node is fading (and this is an indication of the onset of a handover condition), it triggers the AR's in the vicinity to join the multicast group. To avoid packet losses, handover must be detected early enough to provide an adequate time margin before actual handover takes place [13]. Once the mobile node is connected to the new AR, the remaining set of AR's will be removed from the group. However, this paper proposes a solution that reduces such overheads by performing accurate mobility prediction which can select a potential AR. In this paper, the formation of the near optimal multicast tree problem is considered. The main idea is to establish a multicast session from the source to these potential AR's to compute a minimum cost tree with specific constraints. The paper discusses the details of how mobility prediction can help multicast routing that will improve handoff performance.

The rest of the paper is organised as follows. Section 2 presents the Grey Model methodology. Section 3 describes a simulation model for prediction. Section 4 describes the simulation parameters used for mobility prediction. Section 5 describes the spanning tree algorithms. Section 6 presents the framework/architecture. Section 7 describes problem formulation. Section 8 describes the proposed algorithm followed by results and conclusions in section 9 and 10 respectively.

2 Grey Model

In this theory [1][14], the model uses a sequence of raw measurements that are generated by the system under study. The approach is to convert this raw data into a series of meaningful data values, which is done by the Accumulating Generating Operation (AGO) that is a key feature of Grey system theory. The accumulated generating operation is carried out in the following way to create a new series. Let the sum of the first and second elements in the measurement set data be the second element of the new series. Let the sum of the first, second and third element be the third element of the new series and so on. The derived new series is called the Onetime Accumulated Generating series of the original series. Its mathematical relations are presented in Eqs. $(1) - (4)$. Let the original series be

$$X^{(0)} = \{X^{(0)}(0), X^{(0)}(1), \cdots\cdots, X^{(0)}(n)\} \quad (1)$$

which represent the measurements of the received signal strengths obtained from the system, Then the Onetime Accumulated Generating series is

$$X^{(1)} = \{X^{(0)}(0), X^{(1)}(1), \cdots\cdots, X^{(1)}(n)\} \quad (2)$$

Where,

$$X^{(1)}(k) = \sum_{i=0}^{k} X^{(0)}(i) \quad k = 1, 2 \cdots n \quad (3)$$

The superscript of (1) in Eq. (3) in $X^{(1)}(k)$ represents the onetime AGO which is denoted as 1-AGO. If the superscript is (r) then it represents r times AGO and is often denoted as r-AGO. The elements of the r-AGO series are:

$$X^{(r)}(k) = \sum_{i=0}^{k} X^{(r-1)}(i) \quad k = 1, 2 \cdots n \quad (4)$$

The purpose of AGO is to reduce the randomness of the series and increase the smoothness of the series.The following is a first order differential equation model with one variable, which will be denoted by $GM(1,1)$.

$$X^{(0)}(k) + az^{(1)}(k) = b, \quad k = 1, 2 \cdots \quad (5)$$

and $X^{(0)}(k)$ is a grey derivative which maximises the information density for a given series to be modelled.

$$z^{(1)}(k) = \frac{X^{(1)}(k) + X^{(1)}(k-1)}{2}, \quad k = 1, 2 \cdots \quad (6)$$

The whitened differential equation model can be expressed as

$$\frac{dX^{(1)}(t)}{dt} + aX^{(1)}(t) = b \quad (7)$$

Where a and b are constants to be determined. a is known as the developing coefficient and b is known as the Grey input. From ordinary least squares method, we have

$$\hat{a}^T \equiv \begin{bmatrix} a & b \end{bmatrix}^T \quad (8)$$

$$\begin{bmatrix} a & b \end{bmatrix}^T = (B^T B)^{-1} B^T Y_n \tag{9}$$

where B is known as the accumulated data matrix and Y_n is a constant vector.

$$\mathbf{B} = \begin{bmatrix} -\frac{1}{2}\left[X^{(1)}(1), X^{(1)}(2)\right], & 1 \\ \vdots & \vdots \\ -\frac{1}{2}\left[X^{(2)}(1), X^{(3)}(2)\right], & 1 \\ -\frac{1}{2}\left[X^{(1)}(r-1), X^{(1)}(r)\right], & 1 \end{bmatrix}$$

$$Y_n = [X^{(0)}(2), X^{(0)}(3) \cdots X^{(0)}(r),]^T \tag{10}$$

By solving a, b, and the differential equation , we can get the prediction function for the grey system

$$\hat{X}^{(1)}(k+1) = \Big(X^{(0)}(1) - \frac{b}{a}\Big)e^{-a(k)} + \frac{b}{a}, \text{ for } k \geq 0 \tag{11}$$

$$\hat{X}^{(0)}(k+1) = \hat{X}^{(1)}(k+1) - \hat{X}^{(1)}(k), \text{ for } k \geq 0 \tag{12}$$

where $\hat{X}(k+1)$ denotes the prediction of $X(k+1)$ at time $k+1$

3 Simulation Model

In this model, we have selected two base stations A and B, which are separated by D metres. The mobile device moves from one cell to another with a constant velocity and the received signal strength is sampled at a constant distance d_s in meters. The model we are considering includes slow fading. The received signal strengths a_t and b_t (in dB) when the mobile is at a given distance kd_s are given by

$$a_t = K_1 - K_2 \log kd_s + u_t \tag{13}$$

$$b_t = K_1 - K_2 \log (N-k)\, d_s + u_t \tag{14}$$

where $N = D/d_s$.The parameters $K_1 = 0$ and $K_2 = 30$ in dB which are typical of an urban environment accounting for path loss. The simulation parameters used for the movement detection are as shown below.

4 Simulation Parameters

Number of Base Stations	2
Trajectory	Straight Path
Sampling distance	10 m
Distance between base stations	2000 m
Path loss (K)	30 db
Transmitter power	0 dB
Fading Process	Lognormal fading
Standard Deviation (u_k)	8dB

5 Spanning tree algorithm

Consider the network topology shown in Fig. 1. For any multicast connection, the source is the corresponding node and the receiver is a set of candidate routers which are serving the mobile node. There are many algorithms that can be used to choose the minimum number of hops to these destinations in wired and wireless networks. Therefore, the problem of computing the minimum cost tree for a given multicast tree with a source and a set of destinations R can be modelled as a Steiner tree problem [15][16]. When there are additional constraints such as the need for available bandwidth limits on directed link, the problem becomes the directed Steiner problem which has an objective of finding the minimum cost rooted at s and spanning all the nodes in D, which can be defined as follows : Given a directed graph $G = (V, E)$ with a specific source node $s \in V$, and a set of destinations $D \subseteq V$, the objective is to find the minimum spanning tree rooted at s and spanning all the nodes in D.

6 Framework/Architecture

The network model that we consider is a wireline/wireless network with a number of access routers connected together and is shown in the Fig. 1. The Corresponding Node [CN] wishing to send information to the Mobile Node have to send their packets via these access routers. A number of access points [AP] can be connected to the access routers [AR]. Each AP covers a region called a cell area. When a mobile node moves from one AP to the other without changing the AR it is called an intra-AR handoff and when it changes from one AR to another it is called an inter-AR handoff. An access point that is connected to the access router serves a mobile node. A mobile node [MN], throughout its movement join and leave these access points. The access point acts as the radio point of contact to the mobile node. An AR considers that each AP is on a separate subnet [6].

A minimum cost tree will reduce the overall transmission time and will reduce the required bandwidth. Obtaining the network topology graph will be vital and so is the computation of the minimum cost tree. The construction of the network topology graph G requires the selection of a suitable subset of nodes. Once the source has guaranteed the topology graph G, a multi-communication tree i.e., a minimal set of routes to the destination D is computed. If there is only one destination node, a single source shortest path algorithm such as the Dijkstra algorithm can be used on G with source s. Given a graph G constructing a minimum cost tree that covers a specific number of nodes is also called the Steiner tree problem for a given set of nodes in a network. This can be classified as an NP hard optimisation problem. There are a number of heuristic algorithms that have been proposed for the above problem [17] [18].

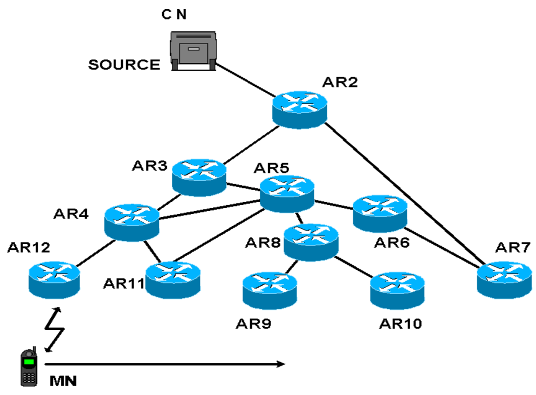

Figure 1: 12 node access router network and problem formulation

7 Problem Formulation

Given a network $G = (V, E), \{c_l = 1/b_l\}_{l \in E}$, a source node $s \in V$, multicast group $M \subseteq V - s$, find a tree **T** rooted at s and spanning all of the nodes in M such that $c(T)$ and the total number of hops from s to all the nodes in M is minimised. $c(T)$ is defined as

$$w_1 \sum_{l \in E} c_l(b_l) + w_2 \sum_{l \in E} c_l(d_l) \qquad (15)$$

where $w_1 + w_2 = 1$ and w_1, w_2 are weighting factors, b_l is the available bandwidth on the link l and d_l is hop count.

8 Proposed Algorithm

8.1 Tree Construction and coding

Prim's or Kruskal's algorithm are perhaps the simplest Minimum Spanning Tree (MST) algorithms and represent the method of choice for dense graphs. Trees are the minimal graphs that connect any set of nodes, thus permitting all nodes to communicate with each other without any redundancies. The key here is to find the shortest distance from each non-tree vertex to the tree. In this problem (Fig. 1) the MST algorithm is modified and used to find the tree for all the destination AR's specified by the mobility prediction algorithm. In this section, two algorithms for evaluating the minimal cost spanning tree (MMP algorithm - Multicast Mobility Prediction) and the least hop count are proposed separately. The pseudocode and a short description is given and is followed by the details of the step by step process in the following section.

8.2 MMP Algorithm:

Input: signal strength values, a set of minimum AR's as predicted by mobility prediction algorithm.
Output: A minimum multicast tree that satisfy the objectives from source to the destination.
Method:

1. Run the grey prediction algorithm to select the potential AR's
2. Run the MST algorithm to find the routes to all the selected AR's
3. Start with source s to all the nodes in $M \subseteq V - s$.
4. Do, $d_i = d_j + c_{ij}$, where i is the current source, until the distance for all nodes is calculated.
5. For every destination; backtrack all the links that will be used in the spanning tree.
6. Mark the link (i, j) where $(d_i > d_j)$
7. Remove unmarked links from the spanning tree
8. Result is a spanning tree from s to nodes in M with minimum cost

Steps involved: Minimum Cost:
Step 1: Start the source with s, compute the distance d_i of the nodes spanned from the current source i to be $d_i = d_j + c_{ij}$ once the distance to all the nodes has been found go to step 2
Step 2: For every destination; back track and mark all the links that will be used in the spanning tree. Mark the link (i, j) if $(d_i > d_j)$ (numbering to track)
Step 3: Remove the unmarked link from the spanning tree or prune the other links that are not supposed to be in the tree. The remaining links form the multicast tree with the minimum cost.

8.3 K-Minhop Algorithm:

The general idea behind our algorithm is to determine the optimal feasible route in the multicast tree from source to the destination. This section describes the algorithm and discuss the working.
Input: A graph $G = (V, E)$ with minimum hop as constraints from a source s to a set of destinations.
Output: A minimum hop count that satisfy the constraints from source to the destination.
Method:

1. Set the costs of the edges to one.
2. For each destination D in M.
3. Run the K-shortest path from source s until destination D is reached.
4. The result is the total number of paths for a given source to destinations

Minimum hop count:
Take the graph G and set all $c_{ij} = 1$ and then find the shortest path from source node s to all destinations D.

Finally, there could be two alternative solutions, one for minimum cost and the other for minimum hops. Solving the minimum cost and minimum hop count problems gives two extreme solutions which may conflict. It is good to find a near optimal tree with respect to these two objectives by exploring all the other trees "between" these two extreme solutions. A set of candidate tree solution can be found by exploring a "*good*" set of solutions from the source s to all the destinations D. This set of "*good*" solutions can be obtained by applying k-shortest path algorithms. For every solution provided, we can get possible routes based on residual bandwidth as well as minimum hop count. Further, the final solution depends entirely on the type of application. For this purpose we give the weights to provide a bias towards one over the other. The cost is evaluated according to Eq.15 and can be summarized as shown:

$$\text{Total Cost} = w_1.c_1 + w_2.c_2, \tag{16}$$

where, $w_1 + w_2 = 1$ and,

- c_1 cost from the MMP algorithm $w.r.t$ the bandwidth,
- c_2 cost from the K-Minhop algorithm $w.r.t$ the number of total hops.
- w_1,w_2 weighting factors.

For a delay sensitive application, such as VoIP one will put a higher weight for w_2 to ensure a tree with minimum hop count is chosen to minimise the end-to-end delay.

9 Results

The results of the Grey prediction are given in Fig.2 and they show a plot of the actual values of received signal strength and the corresponding predicted values. The Grey model tracks the curve with some error. The Grey model does not predict large variations in input data. The variations in the prediction values are shown in Fig. 3 by plotting the absolute error. Using the above results which provide accurate mobility prediction, tree selection will be minimized and this in turn reduces the use of network resources during handoff.

9.1 Numerical Results

The Algorithms presented in the following section were implemented in C++ according to [16]. We performed the tests on a 12 node network as well as a 20 node network. We have compared the performance of the CAR set algorithm against our proposed MMP algorithm. For testing our algorithm, we have considered the 20 node network which in a wired network of AR's as shown in the figure. We consider the selection of nodes from the prediction algorithm is far better than the CAR set as it can reduce the number of AR's and thus reducing the total bandwidth required for multicast. Here, we considered the source node 1 as the corresponding node(e.g. video streaming server) and the rest could be the access routers sending information to the wireless network. We tested our network and the settings as described on a Pentium 4 1.7 GHz PC with 512 MB RAM and the results obtained are summarized in table 1 for the 12 node access router network of Fig. 1. For each test scenario, a network simulation experiment was setup based on the selection of nodes determined by our prediction algorithm. For each experiment we performed and calculated the minimum cost tree for bandwidth and minimum hop count as shown. The table also shows the total cost as per Eq.16 where $w_1 = w_2 = 0.5$. Each row in the table rep-

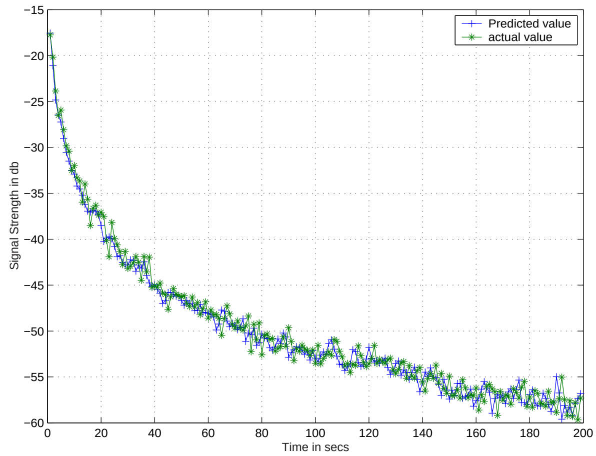

Figure 2: The received signal strength curves of the predicted and actual outputs from the $GM(1, 1)$ model.

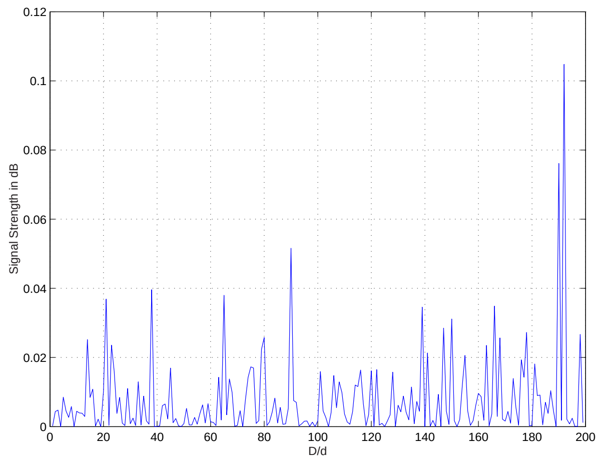

Figure 3: The predicted errors from the $GM(1, 1)$ based model

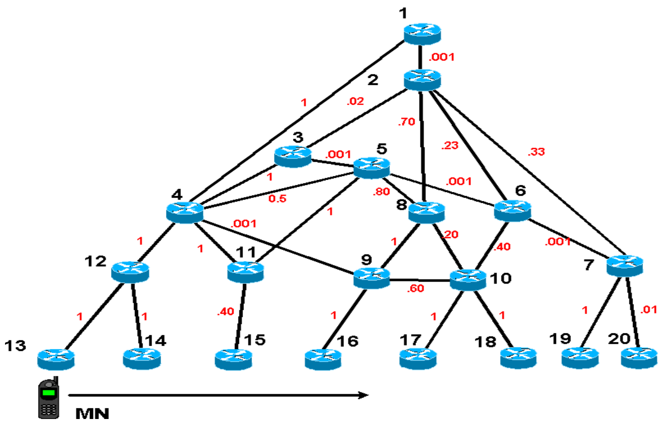

Figure 4: Topology for a 20 access router network

12 Node AR Network proposed MMP algorithm				
	No. of selected nodes by prediction	Residual bandwidth	hop count	total cost
Tree 1	1	1.702	5	3.351
Tree 2	2	2.702	6	4.351
Tree 3	3	4.702	8	6.351
12 Node AR Network - K - minhop algorithm				
	No. of selected nodes by prediction	Residual bandwidth	hop count	total cost
Tree 1	1	2	2	2
Tree 2	2	3	3	3
Tree 3	3	6	6	6

Table 1: Table showing the results from proposed algorithm and K-min hop algorithm for a 12 node access router network of figure 1.

12 Node AR Network - CAR set algorithm				
	No. of selected nodes	Residual bandwidth	hop count	total cost
Tree 1	7	5.704	11	8.351

Table 2: Results from CAR set algorithm for a 12 node access router network of figure 1.

resent a set of tests performed for a given source and a set of destinations. The bandwidth savings are shown in the tables 1 and 2. It can be seen that the results show very good performance of the algorithm proposed in terms of the cost. In addition, we have compared (table 2) the model with the CAR set algorithm which selects all the AR's irrespective of the mobile nodes' movement discussed in [6]. It is worth noting that in all cases the total cost obtained by our algorithm is always less than the CAR Set algorithm. This suggests that it is unnecessary to reserve resources and not to flood the network with multicast packets. However, one disadvantage with this approach is if our prediction algorithm fails. A possible reason for such a failure might be a black spot where there is no received signal strength. The reaction to this situation by the CAR set algorithm could be better as more resources are available with that method. We believe that our prediction algorithm is accurate to within $\pm 0.02dB$ thus it is able to detect the signal strength as well as any other algorithm and matches any other proposed method to the present time. Table 3 and 4 shows the difference between the cost solutions obtained by the CAR set algorithms and our algorithm for a 20 node access router network (Fig.4) and it shows the various scenarios when more nodes are selected by our prediction algorithm.

20 Node AR Network - proposed MMP algorithm				
	No. of selected nodes by prediction	Residual bandwidth	hop count	total cost
Tree 1	1	2.702	6	4.351
Tree 2	2	4.102	8	6.051
Tree 3	3	5.102	9	7.051
20 Node AR Network - K-minhop algorithm				
	No. of selected nodes by prediction	Residual bandwidth	hop count	total cost
Tree 1	1	3	3	3
Tree 2	2	4.4	5	4.7
Tree 3	3	5.4	6	5.7

Table 3: Table showing the results from proposed MMP algorithm and K-minhop algorithm of figure 4.

20 Node AR Network - CAR set algorithm				
	No. of selected nodes	Residual bandwidth	hop count	total cost
Tree 1	7	8.504	14	11.252

Table 4: Results from CAR set algorithm for a 20 node access router network of figure 4.

10 Conclusion

In this paper, we have provided an overview of how mobility prediction and multicasting help to improve handoff performance. The methods of some current algorithms overload the network during handoff. Now with this it is possible to improve handoff in terms of bandwidth savings based on application requirements. Specifically, with this idea of mobility prediction and multicasting we can improve the handoff delay. Considering the above, a problem has been formulated that takes into account a weighted cost involving bandwidth constraints and hop count supported by a prediction method that improves handoff performance in a multicast environment. Accordingly, two algorithms were proposed, the MMP algorithm and the K-MinHop algorithm and results were tabulated.

Wireless multicast is required for a range of advanced wireless applications employing group communications among mobile users. Applying multicast to wireless networks is difficult for many reasons, for example available bandwidth, the user's mobility that could lead to the loss of packets, delay and incorrect routing. Multicast packets to the set of candidate access routers can cause significant overheads by the duplication or replication of packets. Our ongoing and future work will address the above problems. Experiments are also to be conducted to test the performance in terms of handoff delay. In addition, our focus is on the development of good algorithms that enable us to optimise the two techniques jointly to improve handoff in wireless networks.

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