An Algorithm using Join/Prune Mechanisms to Improve Handoff aided by Mobility Prediction in Wireless Networks

Suresh Venkatachalaiah*, Robert Suryasaputra* and Richard J. Harris†
*Centre for Advanced Technology in Telecommunications (CATT)
School of Electrical and Computer Engineering, RMIT University, VIC 3001, Australia
Email: {suresh, robert}@catt.rmit.edu.au
†Institute of Information Sciences and Technology
Massey University, Private Bag 11 222 Palmerston North, New Zealand
Email: R.Harris@massey.ac.nz

***Abstract*— In this paper, we provide a detailed description of an algorithm that implements join and prune mechanisms, which will help to build an optimal multicast tree with QoS requirements during handoff. An analysis is presented to show how mobility prediction can help in the selection of potential Access Routers (AR) with QoS requirements that affect multicast group size and bandwidth cost in the multicast tree. The proposed technique tries to minimise the number of multicast tree join and prune operations. We have examined the performance of this algorithm using simulations in various environments and obtained good performance results. Our results show that the expected multicast group increases linearly with the increase in the number of selected destination access routers (AR) for multicast during handoff. We observe that the expected number of joins and prunes from the multicast tree increases with group size. Thus, for an increased number of destinations, the estimated cost of the multicast tree in a cellular network also increases.**

***Index Terms*— Grey theory, Join/Prune operation, Multicasting, Handoff, Handover, end-to-end delay, Bandwidth cost.**

I. Introduction

In cellular networks, communications between two mobile nodes completely rely on wired backbone and fixed base stations or Access Routers (AR). Cellular networks have limited resources, which need to be conserved. In wireless networks, bandwidth is limited, wireless links are error prone and there are frequent changes in the position of mobile users that can initiate a requirement for a handoff. For example, there are proposed applications that involve online gaming operations (multiple), where players are located at different locations and use their PDA's or handheld devices to participate in the game. In order to solve handoff problems in such applications, a promising technique involves performing mobility prediction [3][4]. Mobility prediction is used to highlight the minimum number of access routers required to build a suitable multicast tree. An important methodology that supports this prediction is the Grey theory. This theory has been widely applied, as it needs only a limited amount of data for the construction of the model. As few as four measurements of the signal strength are required to enable a prediction to be made. It can be shown that the use of this technique can lead to an improvement in performance during handover. The details of these improvements have been presented elsewhere in the literature and are not included within the scope of this paper.

Also it may be noted that there exists a large amount of literature on multicast in wired and wireless networks [17][21]. Most of the multicast protocols are evaluated in terms of bandwidth consumed by the entire process and maximum delay encountered in delivering the message to any member of the multicast group [16][22]. A multicast message can be sent to each member of the group separately, but this wastes bandwidth, as each message has to be sent over the same link several times [5][6]. There is the need for the construction of a minimal spanning tree with only the members of the group or the required number of ARs.

RBMOM (Range Based MObile Multicast) was proposed to support multicast for mobile hosts on the Internet [18]. Here, there is a tradeoff between the shortest delivery path and the frequency of multicast tree re-configurations. RBMOM can be shown to adapt to fluctuations in both host movement and the number of mobile group members. The main motivation is to allow important (necessary) join operations and to reduce the number of unnecessary joins. Thus, the overheads of concern are the join and leave operations for the multicast tree. Obviously, the tree management cost will increase when mobility is higher. With this in mind, our paper discusses the current state of the art in multicast protocols for wireless networks and compares them to several performance metrics.

Several protocols have been proposed for wireless networks [8][9][20]. Although they solve several important problems, some are quite complicated and still have problems in achieving an optimal multicast tree and do not meet necessary QoS requirements. Some of the schemes claim advantages through using a shortest route path algorithm to minimise resources and to achieve QoS. However, whenever the mobility factors involved are high, building the multicast tree may lead to significant overhead requirements. Furthermore, minimum join and prune operations are required so that there is minimum disruption to the multicast tree. In the MMA protocol [19], the authors propose a way to reduce the number of joins

1-4244-0000-7/05/$20.00 ©2005 IEEE.

by calculating the time that the mobile node spends in the previous cell area. Thus, if the expected time for a visiting mobile node is not long enough it does not invoke the join process. In a further extension to the MMA protocol, it not only reduces unnecessary joins but it also reduces the duplication of packets. The MOM protocol [12][13], proposed by Harrison et. al. involves tunnelling of multicast datagrams. This scheme reduces the number of duplicate multicast datagrams and any additional load on the wireless links, which are of low bandwidth. The approach primarily focuses on scalability with respect to the group size, the number of multicast groups and mobile hosts.

In multicast based mobility (M&M)[7] proposed by Helmy et. al. they define a set of protocol suites to enable multiple access routers to receive traffic for the mobile host. Here, a group called the CAR-set (Coverage Access Router set) of access routers is highlighted or selected to provide the necessary coverage to the mobile node so that there is no loss of packets during handoff. However, this method utilises more network resources and there are more access routers selected into the multicast tree. This, in turn, can result in more unnecessary join and prune operations.

In our paper, we propose a mobility prediction algorithm based on the Grey model, which helps in reducing the number of unnecessary join and prune operations by identifying a minimalist set of potential ARs to use for inclusion in the multicast group. The proposed algorithm also takes care of the QoS constraints involved during the join operation and thus helps to reduce overheads. The advance knowledge of the potential new AR will help in avoiding packet losses and accomplishing a new handover more efficiently. Minimising the cost of forming a multicast tree is an important issue [11][23]. When a mobile node wishes to join an existing multicast tree, a route from the existing multicast tree to the node must be computed. This paper deals with the problem of optimally connecting a node to an existing multicast tree such that the selected node (aided by the prediction algorithm) still satisfies the QoS requirements.

In this paper, the formation of a near optimal multicast tree problem is considered which requires predicting the new AR and setting up a path proactively to it. The main idea is to establish a multicast session from the source to these potential ARs in order to compute a minimum cost tree with specific performance constraints. The paper discusses the details of how mobility prediction can help multicast routing that will improve handoff performance in terms of join/prune operations. A new algorithm called MBWDC (Multicast BandWidth Delay Constraint) algorithm is proposed to solve this problem. The remainder of this paper is organised as follows: Section 2 describes the Grey methodology used by our system for mobility prediction. In section 3 we present a mathematical formulation of the problem to be solved. Section 4 describes the proposed MBWDC algorithm in detail. Simulation parameters and an associated framework are presented in section 5. Finally, we provide the results in section 6 which are followed by conclusions and future work in section 7.

II. Prediction Methodology

A. Grey Model

In this theory [3], the Grey modelling approach uses a sequence of raw measurements that are generated by the system under study. A key feature of Grey system theory is to convert this raw data into a series of meaningful data prediction values, that is done via the Accumulating Generating Operation (AGO). The Accumulated Generating Operation is carried out in the following way to create a new series of data values. Let the sum of the first and second elements in the measurement data set 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 equations 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 $X^{(1)}(k)$ shown in Eq. (3) 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 the ordinary least squares method, we have

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

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

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

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

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

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

$$\hat{X}^{(1)}(k+1) = \left(X^{(0)}(1) - \frac{b}{a}\right)e^{-a(k)} + \frac{b}{a}, \qquad (11)$$

$$\hat{X}^{(0)}(k+1) = \hat{X}^{(1)}(k+1) - \hat{X}^{(1)}(k), \qquad (12)$$

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

III. Problem Formulation

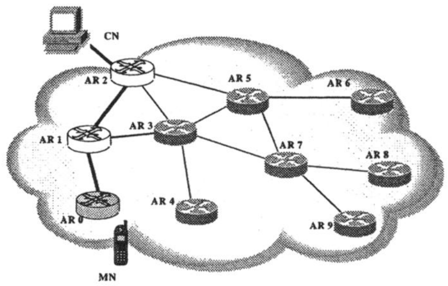

Fig. 1. Topology of 10 node network used in the simulation

We represent a network as a connected directed graph $G = (V, E)$. V and E are the set of n nodes and m links of the network respectively, 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. Figure 1 shows illustrates a multicast tree in which CN is the correspondent node, the grey ones are the selected ARs using the prediction algorithm with thick darker lines showing the path taken and the darker nodes are Steiner nodes(i.e. non-members in-tree nodes).

A path between a particular source v_s and a particular destination v_d is represented by a sequence of nodes $v_s, v_1, v_2, v_3, ...v_d$ where $v_i \subseteq V$. There could be multiple such paths based on a given source and a destination. However, for multicast routing, our focus is on finding such paths between a *single* source and *multiple destinations*, which will simultaneously satisfy the QoS requirements. These paths essentially form a multicast tree. An efficient allocation of network resources satisfying the QoS requirements is the primary goal. Several algorithms that construct low cost multicast routes are based on heuristics for approximate Steiner trees. However, satisfying the individual QoS parameters may be conflicting or may be interdependent making it a more challenging task. If we have a single optimisation factor to be satisfied, such as a residual bandwidth constraint, then the problem is easily solved. But, satisfying different QoS parameters simultaneously is a known NP-Hard problem [11] [21]. In our formulation, the performance of the multicast tree is determined by two factors, viz:

1) bounded end-end delay along the individual paths from the source to the destination.
2) minimum cost of the multicast tree, for example, in terms of residual bandwidth.

The first QoS optimisation factor chosen is the delay bound δ. In our formulation, a delay bound is specified while constructing the multicast tree. We assume the edge cost and edge delay are different functions. Here, the edge cost is the inverse of the residual bandwidth and the edge delay could be the one of the propagation delay, transmission delay, queueing delay or some (weighted) combination of all three delays. Here, we are also trying to use the constrained minimum cost tree with constraints on the individual path delays. With the requirement of stringent delay constraints, it is often required that the delay from the source to any destinations should be within a time bound or a threshold "δ". We can have, $P(v_s, v_d)$, $v_d \in D$, which is the path from source s to destination d in a multicast tree T, then the bounded delay can be expressed as

$$\forall v_d \in D: \qquad \sum_{l \in P(v_s\ v_d)} d(l) < \delta \qquad (13)$$

where $d(l)$ is used to indicate the delay of the link.
The second QoS optimisation factor chosen is the residual bandwidth. Generally, the multicast path that is capable of providing the greatest residual bandwidth is taken as the best choice. The total cost of the residual bandwidth in the network is given by $\sum_{l \in E}(c_l(b_l))$, where c_l is the cost of the link $l \in E$ and b_l is the bandwidth allocated to the different hops along the entire multicast tree T. We notice that $b_l = 0$ if $l \notin p$, where $p \in T$.

A. Problem statement

Given a network $G = (V, E), \{c_l = 1/b_l, d_l)\}_{l \in E}$, a source node $s \in V$, multicast group $M \subseteq V - s$, source to destination delay bound δ, p is the multicast path, find an in-tree node $t \in T$ and a tree T rooted at s such that it minimises the cost $c(T)$ and $\sum_{l \in p}(d_l) < \delta$. $c(T)$ is defined as $\sum_{l \in p}(c_l)$.

B. Host Mobility and tree joining decisions

In our approach, determining the location and speed of the mobile node is very important. The best approach is to use the signal strength available from measurements taken at the Access Points(AP). The mobile host requests a tree join process when the received signal strength of the AP is above the required level and appropriate constraints are satisfied. If the required QoS requirements are met, then the join operation will start with the information received from the mobile host. The decision rule defined above is very simple; when the predicted value of the signal strength and the multiple QoS constraints are met, a mobile host requests a join operation. As part of the connection establishment process, a multicast tree satisfying constraints (factors) 1 and 2 needs to be determined. Our algorithm operates under the assumption that there exists a source node s, and the node to be joined to the tree (in order to execute the handover) should meet the required QoS constraints.

The construction of the initial tree (say T) is based on the selected destination ARs using the mobility prediction algorithm. As a first step, the shortest path from the source s to a destination is noted. If T does not satisfy the requirements of a path with the defined delay constraint, no tree may satisfy it, implying that the delay tolerance is too tight. At this point, it may be necessary to repeat the procedure with the next candidate AR (second best AR). So, a negotiation may be necessary to determine the looser value of the delay bound or select the path that best satisfies the required QoS. Suppose now that the negotiated value of the delay bounds is met for the tree T, it also has to meet the bandwidth requirements. If the two requirements are satisfied the T is considered to have a feasible path for the particular AR and the join operation is completed. It is also possible that the multicast tree may fail to satisfy condition 2. In our approach, an attempt is made to construct the best possible tree with the selected AR using a suitable search algorithm so that it finds the optimal tree and makes a join operation. After the join operation is successful for the mobile node the handover is completed. The following section explains the step by step process of the algorithm implementation shown in fig. 2.

IV. Proposed MBWDC Algorithm and Description

During handover session, the nodes may join/prune from the initial tree which is constructed by using the knowledge of destination nodes given by the mobility prediction algorithm. It is necessary to dynamically update the multicast tree based on the movement of the mobile host and ensure that the delay constraints and the bandwidth cost are satisfied at all times.

Let D be the destination node selected by the mobility prediction algorithm. Figure 2 outlines the proposed MBWDC algorithm. First, all the nodes and edges in the network are initialised and are labelled as *unmarked*. In order to find paths, we construct the l-shortest paths P_i from the node v to s. In lines [3]-[14], for each of the nodes in D, a minimum delay bounded path P_v is determined for each node. The path from a node $v \in D$ to a source node s is found. It is possible that the most suitable candidate AR with good signal strength may not be the best destination AR node, as it may not satisfy the delay bounds. For this reason, all the paths are placed in an ascending order (line [5]). The selection process is based on the acceptable signal strength and required delay bounds. The initial prune operation is made to eliminate all those cases which do not satisfy the delay constraints (lines [7]-[8]). In lines [16]-[18], we construct the multicast tree T based on the paths obtained. In lines [19]-[28], for a particular selected node, the bandwidth costs are evaluated for each path from v to the source. The best route and least cost for bandwidth (p_{best}) is taken as the best AR for handover pruning all the other nodes.

Input : $G = (V, E)$ = graph, s = source node
D = set of destination nodes
N = Number of destination nodes
δ = destination delay bounds threshold
Output: A delay bounded route and a destination node satisfying the constraints and objectives

MBWDC-JOIN($\{G, \delta_l, c_l(b_l)\}_{l \in E}$)
1: $T \leftarrow$ minimum spanning tree with $D \cup s$;
2: Initialise all edges of T as unmarked.;
3: **for** $v \in D$ **do**
4: $P_v \leftarrow$ shortest path from s to v ;
5: Sort P_v in the increasing order delay and label them as $p_1, p_2, \cdots p_k$;
6: **for** $p \in P_v$ **do**
7: **if** $d(p) > \delta$ **then**
8: delete p from P_v ;
9: **end**
10: /* We have set of paths for destination v*/ ;
11: return OK ;
12: **else** return FAIL ;
13: **end**
14: **end**
15: /* we have paths from s to multiple destinations */
16: **for** p_i = *1 to K* **do**
17: Construct a tree T including all the destination nodes D and all links.;
18: **end**
19: $p_{best} = \phi$ /* route from s to a destination */;
20: $c(p_{best}) = \infty$;
21: **for** $v \in D$ **do**
22: **for** $p \in P_v$ **do**
23: $c(p) = \sum_{l \in p} c(b_l)$;
24: **if** $c(p) < c(p_{best})$ **then**
25: $c(p_{best}) = c(p)$;
26: $p_{best} = p$;
27: **end**
28: **end**
29: **end**
30: /*Prune operation*/
31: **for** $l \in p_{best}$ *in T* **do**
32: Mark link l and corresponding tail and head ;
33: Remove all the remaining links and nodes.;
34: **end**

Fig. 2: Proposed algorithm for MBWDC-JOIN

To complete the description of the algorithm, note that if a feasible tree exists, it will provide some path from v to s. Therefore, if the process of path does not satisfy the delay bounds initially, there always exists a second path that can be used. Finally, if the algorithm terminates at line 34, the path returned is a feasible one that exists.

V. Simulation Modelling and Framework

A. Simulation Model

In this model, we have selected two base stations A and B, which are separated by a distance 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 metres. Our model includes slow fading [1]. The received signal strengths a_t and b_t (*in dB*) when the mobile is at a prescribed distance are given by

$$a_t = K_1 - K_2 \log k d_s + u_t \quad (14)$$

$$b_t = K_1 - K_2 \log (N - k) d_s + u_t \quad (15)$$

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 movement detection are as shown in table 1.

B. Simulation Parameters and Network Topology

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

TABLE I

TABLE SHOWING PARAMETERS USED IN THE SIMULATION

The network topologies to be considered in our investigations are shown in Figures 1, 3 and 4 respectively. A number of access points (AP) can be connected to the access routers (AR). When a mobile node moves from one AP to another 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. The access point acts as the radio point of contact for the mobile node. An AR considers that each AP is on a separate subnet [7]. Most studies conducted on mobility use different topologies and scenarios to evaluate their architecture and focus on handover behaviour. In our study, we have defined network topologies with sizes 10, 20, 60 and 100 nodes to test our algorithm. The topologies define the number of nodes and their link connectivity with associated delays and bandwidth costs. A sample of networks with sizes of 60 and 100 nodes are shown in figures 3 and 4 respectively.

VI. Results

The results of the Grey prediction are shown in Fig. 5 which is a plot of the actual values of received signal strength and corresponding predicted values. The Grey model tracks the curve but there is an associated error which is shown in Fig. 6. The Grey model does not predict large variations in the input data. The algorithm presented in the previous section was implemented in C++ using methods and code from [2]. We performed our tests on 10, 20, 60 and 100 node networks. We have compared the performance of the CAR-set algorithm against our proposed MBWDC algorithm. For the testing of our algorithm, we have considered networks that have a wired

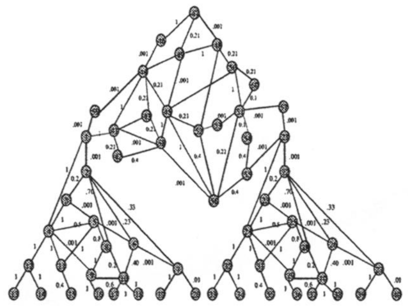

Fig. 3. Topology of 60 node network used in the simulation

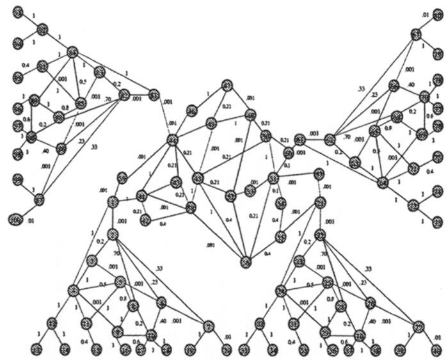

Fig. 4. Topology of 100 node network used in the simulation

network of ARs. The selection of nodes from the prediction algorithm is superior to the CAR-set as it typically reduces the number of ARs and thus reduces the total bandwidth required for the multicast network. Here, we considered a source node as the corresponding node (e.g. a video streaming server) and the remaining nodes could be the access routers sending information to the wireless network. We tested our network and the settings as described using a Pentium 4 1.7 GHz PC with 512 MB RAM and the results obtained are summarised in Table 2 for the 10 node AR network, Table 3 for the 20 node AR network, Table 4 for the 60 node AR network, and Table 5 for the 100 node AR network. For each test scenario, a network simulation experiment was setup based on the selection of nodes determined by our prediction algorithm. In our simulation, the δ value and the bandwidth cost are assigned initially and would remain the same for all destinations. The delays on individual links are generated randomly between 0 and 1. For simplicity, all the links were assumed to be bidirectional and symmetric. Furthermore, all the links were assumed to have enough bandwidth to satisfy the bandwidth constraints.

For each experiment, we performed and calculated the minimum cost tree for bandwidth. In the tables and the graphs plotted, MBWDC-1 represents a single node selection, MBWDC-2 represents a 2-node selection and so on. The tables also show the total cost, hop count, the number of unnecessary joins and the number of paths generated for a given source

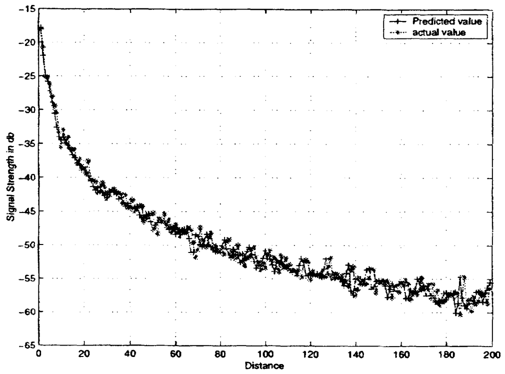

Fig. 5. The received signal strength tracked by the Grey model.

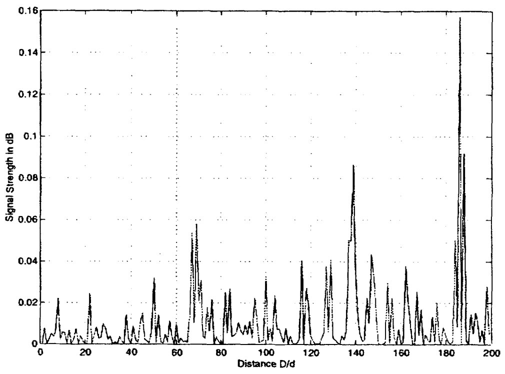

Fig. 6. The absolute error from the Grey model.

10 Node Access Router Network - proposed MBWDC algorithm					
	Selected by prediction	No of Paths	Residual bandwidth	hop count	Unnecessary joins
MBWDC-1	1	7	1.202	5	2
MBWDC-2	2	17	2.202	6	3
MBWDC-3	3	24	3.202	7	4
10 Node Access Router Network CAR-set Algorithm					
CAR-set	7	52	5.202	8	6

TABLE II

OUR ALGORITHM VS CAR-SET ALGORITHM (10 NODE AR NETWORK)

20 Node Access Router Network - proposed MBWDC algorithm					
	Selected by prediction	No of Paths	Residual bandwidth	hop count	Unnecessary joins
MBWDC-1	1	5	2.202	6	3
MBWDC-2	2	20	3.202	7	4
MBWDC-3	3	30	4.602	9	5
20 Node Access Router Network CAR-set Algorithm					
CAR-set	7	60	5.603	11	6

TABLE III

OUR ALGORITHM VS CAR-SET ALGORITHM (20 NODE AR NETWORK)

60 Node Access Router Network - proposed MBWDC algorithm					
	Selected by prediction	No of Paths	Residual bandwidth	hop count	Unnecessary joins
MBWDC-1	1	5	5.743	12	2
MBWDC-2	2	15	6.743	13	3
MBWDC-3	3	25	8.143	13	4
60 Node Access Router Network CAR Set Algorithm					
CAR-set	7	65	9.144	17	7

TABLE IV

OUR ALGORITHM VS CAR-SET ALGORITHM (60 NODE AR NETWORK)

100 Node Access Router Network - proposed MBWDC algorithm					
	Selected by prediction	No of Paths	Residual bandwidth	hop count	Unnecessary joins
MBWDC-1	1	5	1.254	12	3
MBWDC-2	2	18	3.567	14	5
MBWDC-3	3	28	7.476	15	6
100 Node Access Router Network CAR Set Algorithm					
CAR-set	7	70	9.076	18	8

TABLE V

OUR ALGORITHM VS CAR-SET ALGORITHM (100 NODE AR NETWORK)

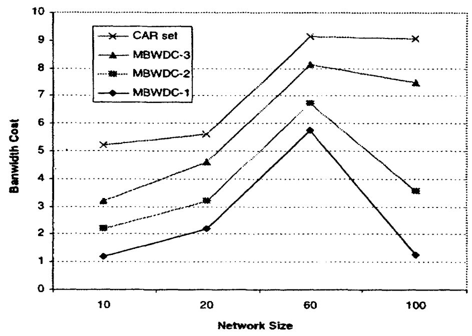

Fig. 7. Bandwidth Cost Vs. Network Size.

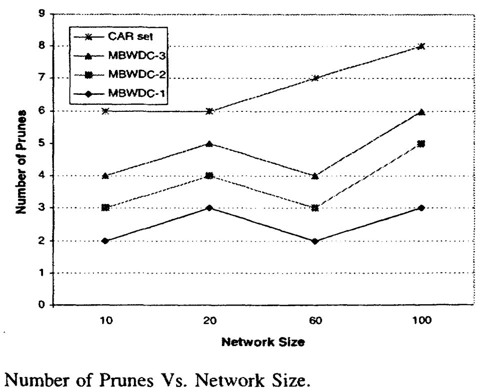

Fig. 8. Number of Prunes Vs. Network Size.

and destination pair for different network sizes. Each row in the table represents a set of tests performed for a given source and a prescribed set of destinations. It can be seen that the results show very good performance by the proposed algorithm in terms of cost. In addition, we have compared the model with the CAR- set algorithm which selects all the ARs, irrespective of the mobile nodes' movement, discussed in [7]. 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 known algorithm and matches any other proposed methods to the present time. All the tables show the various scenarios when more nodes are selected by our prediction algorithm.

We have also plotted the results in terms of bandwidth cost and the number of prunes against the network sizes. In figure 7, the bandwidth cost is plotted against the network size. With an increase in network size the cost also increases. This is because with the increase in network size the tree becomes denser, resulting in more nodes in the paths. If the number of destinations selected by mobility prediction increases there would be more nodes - which is a major factor in our results. We have compared our results in both the graphs against the CAR-set algorithm proposed by [7]. Our results show better performance in terms of bandwidth costs with delay constraints than the CAR-set algorithm. In Figure 8, the number of prunes are plotted against the network size. Again, in comparison to the CAR-set algorithm our algorithm performs better as it selects the most suitable node for prediction to perform the join operation. We argue that the basic reason for the improvement is the selection parameter for the number of highlighted nodes for handover.

VII. CONCLUSIONS

In this paper, we have provided an overview of how a combination of mobility prediction and multicasting helps to improve handoff performance. The problem is formulated by taking into account residual bandwidth as an objective and minimum delay requirements as a constraint. With the help of mobility prediction this improves handoff performance in a multicast environment. The source-destination delay constraint has been considered previously in the context of designing Steiner trees for real-time, multimedia applications, but we are not aware of any work that explicitly considers mobility prediction, bandwidth requirements and delay constraints as parameters to select the optimal tree as applied to wireless networks. By providing the values for parameters such as cost and δ, we can impose a set of constraints on the paths of the multicast tree. Thus, handoff will occur if and only if the tree satisfying these constraints can be found; otherwise the operation will abort. Furthermore, the extra delay incurred from rebuilding a multicast tree can create the possibility of a disruption in data delivery.

This paper proposes an algorithm based on complete topological information for network in order to construct the delay bounded minimum cost tree. The contribution of our work lies in the novelty of using a mobility prediction algorithm for the selection of appropriate ARs and building a multicast tree to improve the performance of handoff. Our algorithm minimises the total link cost of the tree while satisfying delay constraints which could be used for different applications in a wireless environment. The fundamental difference between the CAR-set algorithm and our prediction methodology is a set of access routers that are selected to receive the packets destined for the mobile node. This paper presents an analysis of how mobility prediction helps in the selection of potential ARs with QoS requirements which directly affects the multicast group size and the cost of the multicast tree. Our future work will involve the application of the algorithm to existing protocols such as MIP and HMIP to see if we could improve overall performance in terms of handoff delay and packet losses.

ACKNOWLEDGMENT

The authors wish to thank the Australian Telecommunications Co-operative Research Centre for their financial support.

REFERENCES

[1] T.S.Rappaport, "Wireless communications Principles and practice, 3rd Ed ", Prentice Hall publn, NJ, 1996.
[2] R. Sedgewick, *Algorithms in C++: part 5 - Graph Algorithms*, 3rd ed.Indiana Polis: Addison-Wesley, 2001.
[3] J. L. Deng, "Introduction to Grey system theory," *J. Grey Syst.*, vol. 1, no. 1, pp. 1–24, 1989.
[4] Su, W. and Lee, S. J. and Gerla, M., "Mobility prediction in wireless networks", MILCOM 2000, 21st Century Military Communications Conference Proceedings, 2000, pp. 491-495.
[5] C. L. Tan and S. Pink, "MobiCast: a multicast scheme for wireless networks," *Mob. Netw. Appl.*, vol. 5, no. 4, pp. 259–271,2000.
[6] J. Moy, "Multicast routing extensions for OSPF," *Commun. ACM*, vol. 37,no. 8, pp. 61–ff., 1994.
[7] A.-G. Helmy, M. Jaseemuddin, and G. Bhaskara, "Multicast-based mobility: a novel architecture for efficient micromobility," *Selected Areas in Communications, IEEE Journal on*, vol. 22, no. 4, pp. 677–690, 2004.
[8] C. Chiang and M. Gerla, "Routing and multicast in multihop, mobile wireless networks," in *Universal Personal Communications Record, IEEE 6th International Conference on*, vol. 2, 1997,pp. 546–551 vol.2.
[9] S. Sanyal, L. Nahar, and S. Bhattacharya, "Real-time multicast in wireless communication," in *Parallel Processing, 1997., Proc. of the 1997 International Conference on*, 1997, pp. 500–507.
[10] J. Mysore and V. Bharghavan, "A new multicasting-based architecture for Internet host mobility," in *Proc. of the 3rd annual ACM/IEEE intl. conf. on Mobile computing and networking*, 1997, pp. 161–172.
[11] H.T.Tran and R. J. Harris, "Qos multicast routing with delay constraints," in INOC, Evry, France, 2003.
[12] T. G. Harrison, C. L. Williamson, W. L. Mackrell, and R. B. Bunt, "Mobile multicast (MoM) protocol: multicast support for mobile hosts," in *MobiCom '97:*. New York, NY, USA: ACM Press, 1997, pp. 151–160.
[13] C. L. Williamson, T. G. Harrison, W. L. Mackrell, and R. B. Bunt, "Performance evaluation of the MoM mobile multicast protocol," *Mob. Netw. Appl.*, vol. 3, no. 2, pp. 189–201, 1998.
[14] S. Seshan, "Low-Latency Handoffs for Cellular Data Networks," 1996.
[15] A. Helmy, M. Jaseemuddin, and G. Bhaskara, "Efficient micro-mobility using intra-domain multicast-based mechanisms (M&M)," *SIGCOMM Comput. Commun. Rev.*, vol. 32, no. 5, pp. 61–72, 2002.
[16] S. Ramanathan, "Multicast tree generation in networks with asymmetric links," *IEEE/ACM Trans. Netw.*, vol. 4, no. 4, pp. 558–568, 1996.
[17] M. Parsa, Q. Zhu, and J. J. Garcia-Luna-Aceves, "An iterative algorithm for delay-constrained minimum-cost multicasting," *IEEE/ACM Trans. Netw.*, vol. 6, no. 4, pp. 461–474, 1998.
[18] C. R. Lin and K.-M. Wang, "Scalable multicast protocol in IP-based mobile networks," *Wirel. Netw.*, vol. 8, no. 1, pp. 27–36, 2002.
[19] Y.-J. Suh, H.-S. Shin, and D.-H. Kwon, "An efficient multicast routing protocol in wireless mobile networks,"*Wirel. Netw.*, vol. 7, 2001.
[20] A. Acharya, A. Bakre, and B. Badrinath, "IP multicast extensions for mobile internetworking," vol. 1, pp. 67–74, 1996.
[21] V. P. Kompella, J. C. Pasquale, and G. C. Polyzos, "Multicast routing for multimedia communication,"*IEEE/ACM Trans. Netw.*, vol. 1, 1993.
[22] M. Kodialam, T. V. Lakshman, and S. Sengupta, "Online multicast routing with bandwidth guarantees: a new approach using multicast network flow," *IEEE/ACM Trans. Netw.*, vol. 11, no. 4, 2003.
[23] G. N. Rouskas and I. Baldine, "Multicast Routing with End-to-End Delay and Delay Variation Constraints," Raleigh, NC, USA, 1995.