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Abstract

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Keywords

Research, bandwidth, reservation, IEEE, 802, WiMAX, networks

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Research on Bandwidth Reservation in IEEE 802.16 (WiMAX) Networks

Yi Sun, Yilin Song, Jinglin Shi and Eryk Dutkiewicz

Abstract—**According to the characteristics and QoS requirements of different types of service flows, this paper proposes a dynamic, prediction-based, multi-class, adaptive bandwidth reservation scheme for IEEE 802.16 (WiMAX) networks. The scheme adopts different bandwidth reservation and admission control policies to different types of service flows and therefore guarantees that the real-time sessions have higher priorities than non real-time sessions and that handover sessions have higher priorities than new sessions. In addition, a bandwidth reservation adaptation algorithm is also proposed. The algorithm adjusts the amount of bandwidth reserved for handover sessions according to the current network conditions thus creating a balance between new session blocking rate and handover session dropping rate.**

Index Terms—**bandwidth reservation, IEEE 802.16 (WiMAX), quality of service (QoS)**

I. Introduction

IEEE 802.16 [1,2], which is commonly referred to as WiMAX, is one of the most successful representatives of WMANs (Wireless Metropolitan Area Network). IEEE 802.16 networks have a peak data rate of more than 70 Mbps with 20 MHz carrier bandwidth and the coverage of one single BS exceeds 2 kilometers. Moreover, the IEEE 802.16 standard provides good QoS support, it uses the notion of the "channel" which making bandwidth reservation possible, and supports five different types of service flows: UGS, ertPS, rtPS, nrtPS, and BE. UGS (Unsolicited Grant Polling) service flow is designed to support real-time transactions that generate fixed-size data packets on a periodic basis, such as VoIP without silence suppression; ertPS (Extended Real Time Polling Service) and rtPS (Real Time Polling Service) service flow are designed to support real-time transactions that generate variable-size data packets on a periodic basis, such as VoIP with silence suppression and MPEG; nrtPS (Non Real Time Polling Service) service flow is designed to support delay-tolerant transactions consisting of variable-size

data packets for which a minimum data rate is required, such as FTP; BE (Best Effort) service flow is designed to support non real-time transactions for which no minimum service level is required and therefore may be handled on a space-available basis.

WiMAX networks belong to the family of wireless mobile networks, where users may switch between different cells. Therefore, how to maintain connectivity of communication during handovers becomes one of the key issues, and bandwidth reservation is considered as a possible solution. Experience shows that users are more sensitive to interrupting an ongoing session compared with blocking a new one and therefore network administrators usually have part of the bandwidth in each cell reserved only to support handover sessions, so that handover sessions can have higher priorities to be admitted into the network and utilize the network resources.

Common bandwidth reservation strategies can be divided into two categories: fixed reservation and dynamic reservation. Fixed reservation strategies [3,4] reserve a fixed amount of bandwidth for handover sessions in each cell. They are quite simple and no signaling messages need to be exchanged between adjacent cells. However, fixed reservation strategies can not dynamically adjust the amount of bandwidth reserved according to the network's current condition. Therefore, the network resource utilization is low and the flexibility is poor. Recent research work has focused mainly on the dynamic reservation strategies [5-7]. Dynamic reservation strategies need to exchange signaling messages between neighbor BSs, but they could overcome the poor resource utilization problem of fixed reservation strategies. This is very important for wireless networks where radio resources are relatively scarce.

Most of the existing bandwidth reservation proposals have been designed to cope with the single-type transaction model in Telecommunication Networks and they only distinguish handover sessions and new sessions without distinguishing different types of sessions. As described above, five different types of service flows are defined in the IEEE 802.16 standard. In addition, every type of service flow can be distinguished as either a handover session or a new session. Thus traditional bandwidth reservation schemes can not work well in the IEEE 802.16 networks. How to give each type of service flow in the IEEE 802.16 networks an appropriate priority based on its QoS

requirements has become an emerging issue worthy of further research.

This paper proposes a dynamic, prediction-based, multi-class adaptive bandwidth reservation scheme for IEEE 802.16 networks. The remainder of this paper is structured as follows. In Section 2, a handover prediction algorithm is proposed. Section 3 introduces a multi-class bandwidth reservation strategy. Subsequently, the corresponding admission control algorithm is presented in Section 4. Section 5 proposes an adaptation scheme that adjusts the amount of bandwidth reserved according to the current handover call dropping rate in the network. Section 6 demonstrates our simulation results and conclusions are provided in Section 7.

II. Mobility Prediction Algorithm

Since the bandwidth reservation scheme presented in this paper is based on handover prediction results, we first describe the handover prediction algorithm in this section.

The handover prediction algorithm presented in this paper assumes that mobile terminals can acquire their position information (this information can be gathered by various positioning technologies such as GPS). Every MS (Mobile Station) needs to report its current position to the serving BS (Base Station) periodically, and the BS calculates the moving speed and direction of the MS, according to the current and previous positions of MS. Then the BS estimates the distance between MS and the edge of the cell (every BS records its cell boundary position information) according to the current movement direction of MS. This is shown in Fig 1.

After calculating the distance and speed of the MS, the serving BS can estimate the time that MS would reach the edge of the cell and hence may take handover.

If the predicted handover time drops below a certain threshold, the MS is considered to be in the handover critical state. Then BS computes a handover prediction record <MS_ID, BS_ID, BW_REQ, HO_PROB> for that MS, where MS_ID is the identifier of MS, BS_ID is the identifier of the MS's handover target BS, BW_REQ contains the amount of bandwidth resources needed by different types of service flows (UGS, ertPS, rtPS, nrtPS) for the MS, and HO_PROB indicates the estimated probability that the MS hands over to the predicted target cell, which can be calculated using formula (1) below.

$$HO\_PROB = \frac{\alpha_j - t}{\alpha_j} \qquad if \ t \le \alpha_j \qquad (1)$$

In the formula above, t is the time that the MS needs, to reach the edge of the cell. The parameter α_j is used as a threshold, denoting the size of the handover prediction time window of the corresponding target neighbor cell j. When t is less than α_j, MS
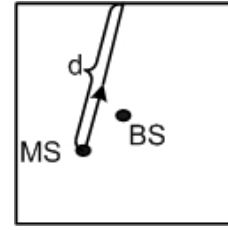

Fig.1. The arrow points to the moving direction of MS and the distance between MS and the edge of the cell is d.

is considered to be in the handover critical state and then resources should be reserved for the MS in the target cell j ahead of the handover event. Different neighbor cells have different α_j, the BS is responsible for maintaining a list of its neighbor cells' α_j. α_j is used to adjust the amount of resources reserved for the handover sessions in the neighbor cell j. Increasing (or decreasing) the value of α_j can result in more (or less) mobile stations being in the handover critical state thus the amount of resources reserved for the handover sessions will increase (or decrease) accordingly.

Formula (1) has two implicit rules:
1) The smaller the distance between MS and its corresponding cell boundary, the shorter the predicted handover time, and therefore the larger the probability of handover. It indicates that the closer MS is to the cell edge, the more likely it is to do a handover.
2) The higher the moving speed of MS, the shorter the predicted handover time, and therefore the larger the probability of handover. It means that the faster the MS moves, the more likely it is to do a handover. Experience shows that it is much harder for high speed moving nodes to change their directions, so the high speed MSs will be more likely to take handovers.

Therefore, formula (1) which is used to estimate the probability of the handover event in this paper matches common experiences well.

In order to reduce BS's computational complexity, the handover prediction algorithm described in this paper has been designed to be simple. However, with the improvement of BS's computation capability, other more complex handover prediction schemes [8,9] can replace the simple algorithm in this paper and this replacement does not have any affect on the performance of the resource reservation scheme described next.

III. Multi-Class Bandwidth Reservation Strategy

Every BS needs to collect the position information of all the MSs in its cell periodically and it generates the corresponding handover prediction record for each MS in the handover critical state. After collecting and analyzing all the records of the predicted handover MSs, the BS calculates the total amount of

resources needed to be reserved in all its neighbor cells for the next period.

Suppose the current cell is cell i, and J represents the set of all its neighbor cells. For each $j \in J$, we utilize formula (2) below to compute the total amount of resources needed to be reserved in cell j for type k service flows of the MSs which are now in cell i but are predicted to handover to cell j.

$$B_{i,j,k} = \sum_{m \in S_{i,j}, k \in F} BW\_REQ_{m,k} \times HO\_PROB_m \quad (2)$$

$B_{i,j,k}$ represents the total amount of resources needed to be reserved in cell j for type k service flows of MSs in cell i which are predicted to handover to cell j in the next period. $S_{i,j}$ denotes the set of all the handover prediction records associated with the MSs in cell i predicting to handover to cell j in the period. $m \in S_{i,j}$ denotes such a record. F denotes the set of the four different types of service flows {UGS（No.1.1）, ertPS（No.1.2）, rtPS（No.1.3）, nrtPS（No.2）} in IEEE 802.16, $k \in$ {1.1, 1.2, 1.3, 2}. $BW\_REQ_{m,k}$ is the amount of resources needed by type k service flows indicated in the handover prediction record m, HO_PROB_m is the estimated handover prediction probability in record m.

After calculating $B_{i,j,k}$ with formula (2), the BS of cell i notifies the BS of its neighbor cell j with this result. At the same time, cell i also receives bandwidth reservation requests from all of its own neighbor cells.

When a BS (BS of cell j, for example) has received bandwidth reservation requests from all of its neighbor cells, it then calculates the amount of resources that need to be reserved in its cell for different types of handover service flows in the next period by formula (3) below.

$$G_{j,k} = \sum_{k \in F, i \in I} B_{i,j,k} + T_{j,k} \quad (3)$$

$G_{j,k}$ represents the total amount of bandwidth reserved in cell j for type k service flows and it is composed of two parts: the first part is the sum of the bandwidth requests from all the neighbor cells, while the second part T_k is a parameter used to adjust the amount of bandwidth reserved for type k service flows according to the current handover call dropping rate. The method to compute T_k is introduced in Section 5. I denotes the set of all the neighbor cells of cell j.

Note that in order to prevent the network bandwidth from being occupied excessively by a single type of service flow, the proposal in this paper let BS reserve bandwidth for different types of service flows separately. In addition, $G_{j,k}$ calculated by formula (3) is only a target value which may not be equal to the actual amount of bandwidth reserved. $G_{j,k}$ is greater than the actual amount of bandwidth reserved for type k service flow when there are no enough bandwidth resources in the current cell to fulfill all the bandwidth requests for different types of service flows.

Adopt multi-class reservation policy and divide the reserved bandwidth for different types of handover service flows in cell j into two classes: $G_{j,1}$ and $G_{j,2}$, where $G_{j,1}$ represents the sum of the bandwidth reserved for UGS, ertPS and rtPS handover service flows (real-time transactions), and $G_{j,2}$ is the bandwidth reserved for nrtPS handover service flows (non real-time transactions). $G_{j,1}$ is composed of 3 parts: bandwidth reserved for UGS handover service flows $G_{j,1,1}$, bandwidth reserved for ertPS handover service flows $G_{j,1,2}$, and bandwidth reserved for rtPS handover service flows $G_{j,1,3}$.

IV. Call Admission Control Algorithm

Based on the bandwidth reservation strategy proposed in Section 3, a corresponding call admission control algorithm is designed to ensure that different types of service flows have different priorities to access the network and utilize the network resources.

For UGS, ertPS, rtPS handover service flows, if one of the following two conditions is met, the request will be accepted. Otherwise, the request will be rejected.

$$\begin{cases} C_{j,avail} - \sum_{q=1, q \neq i}^{3} G_{j,1.q} \geq R_i & if \ C_{j,avail} \geq \sum_{q=1}^{3} G_{j,1.q} \\ C_{j,avail} \times \dfrac{G_{j,1.i}}{\sum_{q=1}^{3} G_{j,1.q}} \geq R_i & otherwise \end{cases} \quad (4)$$

$C_{j,avail}$ denotes the amount of bandwidth currently available in cell j, and R_i represents the amount of bandwidth required by the handover service flow (type 1.i), which tries to get access to the network. The first condition is used in the situation when the amount of available bandwidth in the cell is greater than the total amount of bandwidth needed to be reserved for all the three types of Class 1 handover service flows. Under this situation, handover sessions can make use of not only the bandwidth reserved for their own type (type 1.i), but also any spare bandwidth in excess of the total $G_{j,1}$. In contrast, the second condition is used in the situation when the amount of current available bandwidth in the cell is less than the total amount of bandwidth needed to be reserved for all the three types of Class 1 handover service flows. Under this situation, to ensure the fairness among different types of Class 1 handover service flows accessing the network, the BS assigns the available bandwidth resources according to the proportion of bandwidth requirements for each type of Class 1 handover service flows.

For nrtPS handover service flows, only if the following condition is met, the request will be accepted. Otherwise, the request will be rejected.

$$C_{j,avail} - G_{j,1} \geq R \quad (5)$$

R represents the amount of bandwidth required by the nrtPS

handover service flow which tries to get access to the network. $G_{j,1}$ is the total amount of bandwidth needed to be reserved in cell j for all the three types of Class 1 handover service flows. As can be seen from formula (5), it is obvious that nrtPS handover service flows have a lower priority to get access to the network than that of UGS, ertPS and rtPS handover service flows. Only when the cell still has enough spare bandwidth resources left, after all the bandwidth reservation requests for Class 1 handover service flows are fulfilled, can the nrtPS handover service flow be permitted to access the network.

For BE handover service flows and all types of new service flows, only if the following condition is met, the request will be accepted. Otherwise, the request will be rejected.

$$C_{j,avail} - G_{j,1} - G_{j,2} \geq R \qquad (6)$$

R represents the amount of bandwidth required by the BE handover service flow or the new service flow which tries to get access to the network. $G_{j,1}$ is the total amount of bandwidth needed to be reserved in cell j for all the three types of Class 1 handover service flows and $G_{j,2}$ is the amount of bandwidth needed to be reserved in cell j for nrtPS handover service flows. It can be seen from formula (6) that new service flows and BE handover service flows have the lowest priorities to be admitted into the network.

As described above, the admission control algorithm in this paper provides the real-time handover service flows with the highest priorities to get access to the network, to the best effort ensuring the continuous connectivity of this kind of service flows. Non real-time handover service flows have the second highest priorities while the new service flows and BE handover service flows have the lowest priorities. However, our algorithm does not distinguish between real-time new service flows and non real-time new service flows, since real-time service flows are in essence not more important than non real-time ones. But real-time service flows are more sensitive to call dropping events. Thus, they should be protected from forced terminating when they hand over to a new cell. As to the new real-time service flows and new non real-time service flows, they should have the same priorities to be admitted into the network.

V. Bandwidth Reservation Adaptation Algorithm

To maintain a balance between the handover call dropping rate and the new call blocking rate, a bandwidth reservation adaptation algorithm is presented to dynamically adjust the amount of bandwidth reserved according to the current network conditions.

As described in Section 3, the reserved bandwidth for different types of handover service flows can be divided into two classes. Then two thresholds are defined for each class as MAXPi and MINPi respectively, where MAXPi represents the acceptable upper bound of the handover call dropping rate for Class i service flows, and MINPi represents the corresponding lower

Table 1: Dynamic bandwidth reservation adaptation algorithm

T = 0;
Record N_1、N_2、N_{d1}、N_{d2} in this period of time;
$P_{f1}= N_{d1}/ N_1$;　　$P_{f2}= N_{d2}/ N_2$;
if (P_{f1}>=MAXP1 && P_{f2}<MINP2)
　　then T = T + Step;
else if (P_{f1}<MINP1 && P_{f2}>=MAXP2)
　　then T = T – Step;
else if (P_{f1}>=MAXP1 && P_{f2}>=MINP2 ‖ P_{f1}>=MINP1 && P_{f2}>=MAXP2)
　　then notify the neighbor cells to increase α ; T = 0;
else if (P_{f1}<MINP1 && P_{f2}<MAXP2 ‖ P_{f1}<MAXP1 && P_{f2}<MINP2)
　　then notify the neighbor cells to decrease α ; T = 0;

bound of the handover call dropping rate for Class i service flows.

The BS of each cell will record N_i (the number of Class i handover calls in each period in its cell) and N_{di} (the number of Class i handover calls dropped due to the lack of bandwidth in each period in its cell), and then compute P_{fi} (the handover call dropping rate of Class i service flows) by formula (7).

$$P_{f1} = \frac{N_{d1}}{N_1} \qquad P_{f2} = \frac{N_{d2}}{N_2} \qquad (7)$$

Our dynamic bandwidth reservation adaptation algorithm is shown in Table 1.

Finally, estimate $T_{j,k}$ in formula (3) by formula (8)-(9):

$$T_{j,1} = T \qquad T_{j,2} = -T \qquad (8)$$

$$T_{j,1.i} = \frac{G_{j,1.i}}{\sum_{q=1}^{3} G_{j,1.q}} \times T_{j,1} \qquad (9)$$

As is described in Table 1, there are altogether two different methods to adjust the amount of bandwidth reservation:
1. If one of the two classes of handover service flows has a very high call dropping rate (>=MAXP), while the call dropping rate of the handover service flows of the other class is at a low level (<MINP), then it could increase or decrease T to realize the borrowing between the bandwidth reservation of these two classes of service flows.
2. If one of the two classes of handover service flows has a very high call dropping rate (>=MAXP), while the call dropping rate of the handover service flows of the other class is also at a relatively high level (>MINP), then it could increase the handover prediction time window size α (as illustrated in the handover prediction algorithm described in Section 2) for the neighbor cells to augment the amount of bandwidth reserved for handover calls in the current cell. On the contrary, decreasing the handover

prediction time window size α for the neighbor cells would reduce the amount of bandwidth reserved for the handover calls in the current cell.

VI. Simulation Results

In order to verify the validity of the scheme in this paper, a simple simulation scenario is designed as follows.

- Assumption 1: As shown in Fig. 2, there are 8*8=64 square cells in the simulation scenario and the diameter of each cell is 1 kilometer. We also assume that all the cells are connected circularly. For example, a mobile node will move into cell C07 from the right border, if it traverses the left border of cell C00.
- Assumption 2: The arrival of new sessions is Poisson distributed and the corresponding parameter is λ (sessions/second). The original positions of new sessions are evenly distributed in the scenario area.
- Assumption 3: A new session can be one of the 5 types of (UGS, ertPS, rtPS, nrtPS, BE) with equal probability of 20% for each type and its bandwidth requirement can be 1BU, 2BU, 3BU or 4BU with equal probability of 25% for each value.
- Assumption 4: Initially, the mobile node can choose to move in one of the four directions (UP, DOWN, LEFT, RIGHT) with equal probability of 25%. Then the mobile node recalculates its moving direction every 5 seconds. At each time, the node chooses to move along the current direction with probability of 75%, turn left, turn right each with probability of 10%, and turn around with the probability of 5%.
- Assumption 5: The holding time of the sessions is exponentially distributed, with the corresponding parameter of 120s.
- Assumption 6: The total amount of bandwidth resources in each cell is 25BU.
- Assumption 7: BS recalculates the handover prediction records of all the mobile nodes in its cell and exchanges the requests of bandwidth reservation with its neighbor BSs every 5 seconds.
- Assumption 8: For simplicity, all the mobile nodes in the scenario have the same moving speed.
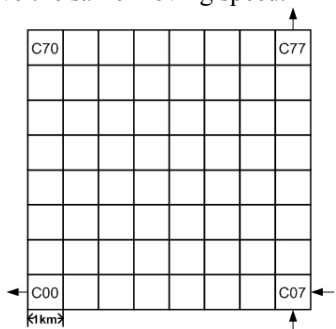

Fig 2. Simulation scenario

A. Call Blocking Rate vs. New Call Arrival Rate

The simulation parameters are defined as follows: the speed of mobile nodes is 20 meter/second and the handover prediction time window size is 7.5 second. The simulation time is 1 day, and the corresponding results are shown in Fig 3.

As shown is Fig 3, with the increase of the new call arrival rate, the network payload intensity goes up, so the new call blocking rate (P_b) and handover call dropping rate (P_f) of different types of service flows all increase accordingly. The group of curves on the bottom of Fig. 3 depict the handover call dropping rates of the three different types of Class 1 real-time service flows (UGS, ertPS, rtPS), the curve in the middle of Fig.3 depicts the handover call dropping rate of Class 2 non real-time service flows (nrtPS), and the group of curves on the top of Fig. 3 depict the handover call dropping rate of BE service flows and new call blocking rates of all the different types of service flows. Thus it can be seen that our scheme can indeed strictly distinguish between different kinds of calls and assign them with different priorities to get access to the network and reserve bandwidth. The distinguishing effect becomes more obvious as the system payload intensity increases.

B. Call Blocking Rate vs. Moving Speed of MS

The simulation parameters are defined as follows: new call arrival rate λ =5 sessions/second, the handover prediction time window size is 10 second and the simulation time is 1day. The corresponding results are shown in Fig. 4.

As shown in Fig. 4, the handover call dropping rate of Class 1 real-time service flows declines slightly (about 4%) as the moving speed of mobile nodes increases, whereas, the call blocking rate of service flows with low priorities increases somewhat (about 2%). This is because more handover events occur during a session's lifetime as the moving speed of the mobile node increases. Therefore, more resources in the network will be reserved or occupied by handover calls with high priorities, resulting in the decrease of the high-priority handover call dropping rate and a slight increase of the low-priority call blocking rate. However, as shown in Fig.4, our scheme can ensure that the call blocking rates of all the different kinds of service flows vary in a small range (the rise is no more than 2% in the figure), even when the moving speed of all the mobile nodes in the network has increased from 5m/s (bicycle) to 50m/s (bullet train). So it can be concluded that our scheme is not sensitive to mobile node's moving speed and it can work well not only in the low-speed environment but also in the high-speed environment.

C. Call Blocking Rate vs. Handover Prediction Time Window Size

The simulation parameters are as follows: new call arrival rate λ =5 sessions/second, the speed of mobile nodes is 20 meter/second and the simulation time is 1day. The corresponding
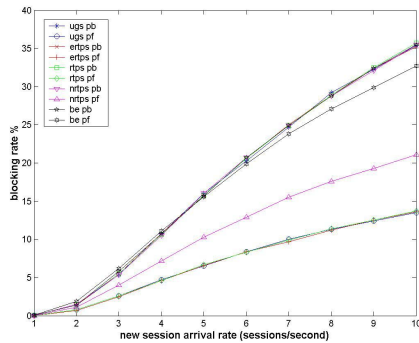
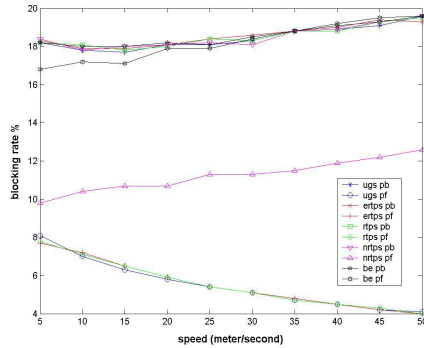Fig. 3. Call blocking rate vs. new call arrival rate
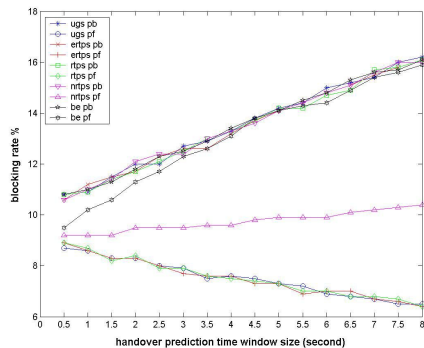

Fig 4: Call blocking rate vs. moving speed of MS

Fig5: Call Blocking Rate vs. Handover Prediction Time Window Size

results are shown in Fig. 5.

As concluded from Fig. 5, increasing the size of the handover prediction time window results in more mobile nodes entering into the handover critical state. Therefore, more bandwidth is reserved for handover calls and the handover call dropping rate can be reduced with a slight rise of the new call blocking rate at the same time. On the other hand, by decreasing the size of the handover prediction time window reduces the new call blocking rate and slightly increases the handover call dropping rate. So it is feasible to balance the new call blocking rate and handover call dropping rate by adjusting the size of the handover prediction time window.

VII. CONCLUSION

IEEE 802.16 (WiMAX) networks are considered as the transitional technology toward 4G network. The IEEE 802.16 standard is designed with good QoS support and it uses the notion of the "channel", thus making it possible to perform bandwidth reservation.

This paper proposed a dynamic, prediction-based, multi-class, adaptive bandwidth reservation scheme for the different types of service flows in the IEEE 802.16 networks. It first introduced a simple handover prediction algorithm, then according to the prediction results, our scheme adopts a multi-class bandwidth reservation and call admission control policies to ensure that different types of service flows have different priorities to access the network and utilize the system resources. In addition, this paper also demonstrated an algorithm to dynamically adjust the amount of bandwidth reserved based on the current handover call dropping rate in the system, so as to achieve a balance between the new call blocking rate and the handover call dropping rate.

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