# Adaptive Cost-based Routing Algorithm for WiMAX IEEE 802.16j MMR Networks

Ben-Jye Chang[1], Shin-Shun Su[2], Ying-Hsin Liang[3] and De-Yu Wang[4]

[1] National Yunlin University of Science and Technology, Institute of CSIE, changb@yuntech.edu.tw
[2,4] Chaoyang University of Technology, Department of CSIE, {s9527631,dywang}@cyut.edu.tw
[3] Nan-Kai University of Technology, Department of CSIE, t136@nkut.edu.tw

*Abstract***—**Based on IEEE 802.16e standard, WiMAX proposed a relay-based approach, namely, the IEEE 802.16j standard, to extend the service area of Base Stations (BSs) and to improve the quality of RSS, and then achieved the advantages of low-cost and compatible with existing WiMAX protocol. According to the different features on mobility and relay range, Relay Station (RS) can be classified into three types: Fixed RS (FRS), Nomadic RS (NRS) and Mobile RS (MRS). Since a relay-based WiMAX network includes different types of RSs, how to efficiently construct the relay-based WiMAX and how to determine an optimal routing path between a Mobile Station (MS) and the MR-BS become two important issues. This paper thus proposed an IEEE 802.16j-conformed relay-based adaptive cost-based routing approach, in which a multihop optimal path is selected in terms of link bandwidth, path length and channel condition. Numerical results demonstrated that the proposed routing approach significantly outperforms other approaches in Fractional Reward Loss, network utilization and average end-to-end path delay.

Keywords—IEEE 802.16j, RS, MR-BS, adaptive routing, path cost

## 1. INTRODUCTION

A Wireless Metropolitan Access Network, defined by IEEE 802.16, has been extensively promoted recently. IEEE 802.16e [2] achieves the advantages of supporting high mobility (120km/hr) and expanding wireless transmission range (5km). Moreover, all kinds of the related mobile communication applications, e.g., real-time video service, VoIP, dynamic vehicle navigation, etc., are expected and they would also bring more convenience in communication system. However, signal fading, attenuation, path loss caused by some hiding areas (e.g., skyscrapers, hills, narrow alleys, etc.) or near cell boundary result in reducing transmission quality, and data rate.

How to guarantee connection data rate even though be beyond original service zone with low-cost solution is the most concern. In previous studies, for solving the above-mentioned problem, an identity cell (or repeater) was adopted but significantly increases cost and may increases signal interference.

The IEEE 802.16j standard proposes a low cost relay mechanism to increase the coverage outside the MR-BS range (i.e., increase coverage with low cost relay deployment) and increase the transmission quality in the relay zone. Table I compares the advantages and disadvantages among the solutions of using BS, RS and Repeater. In RS, three types of RS: FRS, NRS and MRS are differentiated from RS mobility. For instance, FRS fixedly deploys relay nodes, especially for the area with serious signal attenuation. NRS is designated for the node with slow mobile or temporarily stop. MRS is used for public transit for effectively serve more MSs and reduce the relay deployment cost.

TABLE I. The characteristics comparison among BS, RS and Repeater

| | **Advantage** | **Drawback** |
|---|---|---|
| Base Station | ・Service range widely<br>・Capability complete | ・Higher cost |
| Relay Station | ・Low cost<br>・Extended service range<br>・Construction faster | ・Capability incomplete<br>・System more complex |
| Repeater | ・Low cost | ・Interference expanded |

Previous works on multi-hop relay path selecting can be classified into three categories: high-reliability routing, load-balancing QoS routing and IEEE 802.16j-based multi-hop relay routing. **In the related works of high-reliability routing**, [3] treated multi-metrics as the evaluation factors but only improves small transmission coverage by using fixed Access Point (AP). Additionally, when it considers each impact factor, normalization is not applied for evaluating. This may cause unfair results.

[4-6] determines a routing path according to different network environments, but they are lack of a systematic mechanism for computing optimal weights that could achieve the best result.

For preventing over-loading on some paths, [7]-[8] considers average bandwidth utilization for multihop fixed relay network. Because their network models view the network as a mesh model, [7]-[8] can not applied to the IEEE 802.16j Mobile Multi-hop Relay (MMR) networks framework.

[9-10] discuss the path selection problem in WiMAX relay networks, in which RSs are adopted to extend network topology. To achieve the optimal network throughput, the path with the highest access/relay link transmission rate from MR-BS to MS is selected as the routing path. However, the path determination used in [9][10] are the centralized schemes that increase polling delay and make the resource management difficult, when a large number of RSs is deployed within a MR-BS. Thus, [11] proposes a distributed scheme to determine routing path to reduce signaling delay while managing radio resource efficiently.

Although the approaches proposed in above studies can extend the coverage and improve the transmission quality by deploying Fixed-type RSs, they don’t meet the mobile RS feature supported in the IEEE 802.16j specification [1]. Specifically, IEEE 802.16j offers different types of RSs that makes the multihop path determination more complicated; especially, the inter-RS handoff issue caused by RSs moving should be addressed. Thus, this paper proposes an adaptive cost-based routing algorithm that satisfies the IEEE 802.16j features, and achieves some advantages: (1) considering non-transparent transmission mode, (2) three types of RSs, (3) Adaptive Modulation and Coding (AMC) and (4) bandwidth allocation. As a result, the approach achieves low blocking and high utilization under various impact factors. Moreover, we consider path re-selection when MS/RS performs inter/intra MR-BS/RS handoff.

The remainder of this paper is organized as follows. The network model of our strategy is proposed in Section 2. Section 3 details the proposed adaptive cost-based routing approach. Numerical results of the proposed algorithm and all compared approaches are provided in Section 4. Conclusions and future works are given in Section 5.

# 2. NETWORK MODEL

In this section, we first describe the IEEE 802.16j MMR networks characteristics and network model of our strategy. Next, we will define some useful notations. Finally, the performance metrics for evaluating the proposed approach and the IEEE 802.16 specification are defined in detail.

IEEE 802.16j is the standard for WiMAX Mobile Multihop Relay (MMR) networks. Through the deployment of RSs and MR-BS, IEEE 802.16j can extend the service zone outside the MR-BS’s transmission range and improve the transmission quality for the high-interference areas, while does not increase the system cost because the cost of the RS deployment is much cheaper than that of MR-BS. IEEE 802.16j supports two transmission modes of RS: the transparent (i.e., T-RS) and non-transparent (i.e., NT-RS) modes. In the transparent mode, a T-RS acts as a forwarding relay node; however, in the non-transparent mode, the NT-RS acts as a small-scale BS having the capability to allocate bandwidth to MSs and sending its preamble, Frame Control Header (FCH) and MAP information. The synchronization operation is accomplished by utilizing Relay amble (R-amble) [12]. RSs operating in a compound of centralized and distributed scheduling shall not mixed along a single path i.e. it shall not be allowed for an RS to apply centralized scheduling if there is an RS on the same path with distributed scheduling and vice versa[1]. In addition, the delay latency between the MR-BS and MSs in NT-RS mode’s distributed path selection mechanism is less than that in T-RS mode’s centralized mechanism. Thus, this work focuses on the NT-RS mode for its efficiency.

Fig. 1 demonstrates the relay-based frame architecture used in IEEE 802.16j. The Downlink Sub-frame and Uplink Sub-frame can be divided into Access Zone and Relay Zone, respectively. In the aspect of data transmission in the Downlink Sub-frame, a BS directly distributes bandwidth to a MS with the Downlink Access Zone, which does not need an RS or utilize the supported Downlink Relay Zone to transmit the data to the RS. Then, the RS can use its Downlink Relay Zone to relay the data down to MSs. In the aspect of data transmission in Uplink Sub-frame, a MS can transmit the data to RS or BS with Uplink Access Zone. If the MS cannot communicate with BS directly, the RS located in the Uplink Relay Zone can relay the MS's data to the BS.

Some useful notations are defined as follows.

$k$ : The service class, $1 \le k \le K$ , where $k$ = 1 is the lowest high priority and $k$ = $K$ is the highest priority.

$\lambda_k$ : The arrival rate of $k$ class services flow.

$RW_k$ : The reward of class $k$ service flow.

$B_k$ : The blocking rate of class $k$ service flow.

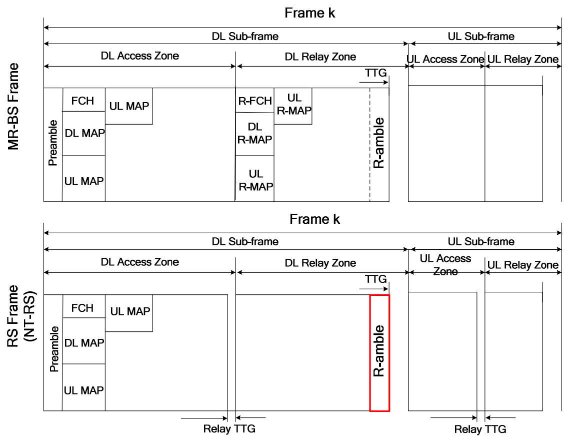


Fig. 1. IEEE 802.16j MMR frame structure

Finally, three important performance metrics, including Fractional Reward Loss (FRL), average bandwidth utilization and average path delay are adopted for comparing the proposed approach with other approaches.

First, we adopt the Fractional Reward Loss (FRL) [13] to evaluate the performance. FRL can be viewed as weighted blocking probability in which a call is given a weight based on its reward. For instance, the reward of a high class required call should be higher than the reward of a low class required call. In general metric of blocking probability, different classes of traffic bring the same reward, which is unfair and lacks of precise. Consequently, FRL is formulated as

$$FRL = \frac{\sum_{k=1}^{K} RW_k \lambda_k B_k}{\sum_{k=1}^{K} RW_k \lambda_k} \qquad (1)$$

Minimizing the fractional reward loss is equivalent to maximize the expected revenues produced by the network system.

Second, the utilization of a WiMAX network, $W$ , is examined, which is defined by

$$Utilization = \frac{Allocated\_BW(W)}{MR-BS_{CAP_w}} \qquad (2)$$

where *Allocated_bandwidth(W )* is the average allocated bandwidth of the MMR networks. More utilization means better performance.

Third, the average path delay time is evaluated, in which a node delay ( $d_{nodal}$ ) consists of four factors:

$$\begin{aligned} d_{nodal} &= d_{process} + d_{queue} \\ &\quad + d_{transmission} + d_{propagation} \end{aligned}, \qquad (3)$$

where $d_{process}$ is the process delay, $d_{queue}$ is the queue delay of the node, $d_{transmission}$ is the frame transmission time and $d_{propagation}$ is the link propagation delay. Clearly, the path delay increases as the number of hops increases, and may cause not to meet the delay bound of real-time services.

# 3. COST-BASED ADAPTIVE ROUTING PATH SELECTION APPROACH

This section first describes the motivations of this work, and then details the proposed cost-based approach for determining the optimal routing path in WiMAX MMR networks.

For achieving mobile access via multihop relays and thus improving coverage transmission quality, the IEEE 802.16j MMR network consists of three types of RSs: FRS, NRS and MRS. Although more number of RSs can achieve above mentioned advantages, various relay types significantly affect the path determination result and network revenue. The issues of distributedly determining an optimal routing path from MS to MR-BS and efficiently allocating bandwidth of NT-RS become more complicated and important in the IEEE 802.16j MMR network. This motivates us to propose a distributed competitive on-line routing algorithm for an MS to determine an optimal routing path in the IEEE 802.16j MMR network, and thus achieves adaptive routing and maximizes network revenue. The proposed cost-based adaptive routing algorithm adopts a competitive on-line approach to define the link cost according to the relay link residual bandwidth. Because of simultaneously considering the residual bandwidth, path hop-count and AMC channel condition, the proposed approach is not required setting different weight values for individual impact factor. Compared with [4][5][6][9], the most advantage of the proposed approach is not required determining the optimal path by the static weighting scheme. The diverse results by the weight distribution, therefore, can be avoided. The proposed approach is detailed into two parts. First, the considered impact factors: reliability, delay, load balancing and AMC rate, are analyzed. Second, the competitive on-line (COL) cost function is defined for link cost and then applies to the formulation of path cost.

### 3.1. Different impact factors

Based on the focused NT-RS mode, a distributed scheme is proposed for MSs to adaptively determine a routing path while considering four impact factors: reliability, delay, load balancing and AMC coding rate, as detailed below.

#### A. High Reliability:

In IEEE 802.16j, three types of RSs: FRS, NRS and MRS, offering different reliabilities are defined for improving signal attenuation and path loss. For instance, the FRS always supports the most stable transmission power and quality, and thus yields the highest reliability. Conversely, the MRS is moved dynamically and leads to the lowest reliability. Finally, we set the RS priority as FRS>NRS>MRS, and the RS link weight is set as indicated in Table II. Fig. 2 demonstrates an example of the determination of the path reliability, in which the least path weight value means the optimal path, i.e., the lower path.

TABLE II. RS path weight index table

| Type weight | *Fixed RS* | *Nomadic RS* | *Mobile RS* |
|---|---|---|---|
| Fixed RS | 2 | 6 | 11 |
| Nomadic RS | 6 | 10 | 15 |
| Mobile RS | 11 | 15 | 20 |

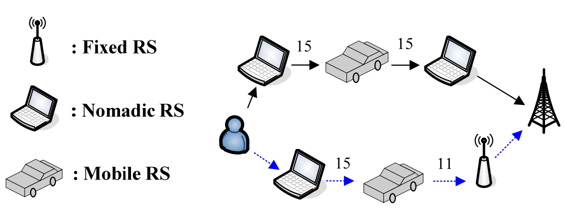


Fig. 2. The determination of path reliability

#### B. Low Delay:

The traffic classes can be divided into the real-time and non real-time traffic classes. The main difference is that the end-to-end delay of the real-time traffic should be less than a specified delay bound, but the non real-time doesn't. Normally, a nodal delay consists of four parts: transmission delay, propagation delay, process delay and queuing delay. As a result, the hop count of a path significantly affects the end-to-end delay, i.e., less the hop count a path has, less the delay the path yields. If several paths exist between a MS and the MR-BS, the path with the least hop-count will be the highest priority one.

#### C. Load balancing:

With limited network resources, the bandwidth resources of the MR-BS and RSs can not always satisfy the MS's request. In a distributed network, MSs may always select the path with the least hop-count firstly, and thus causes that the RSs on the path significantly consume their bandwidth. This unbalanced bandwidth utilization easily causes connections blocking/dropping even though the available bandwidth of the other RSs not on the shortest path are enough for these connections. In consequence, the load balancing should be considered in the path determination. In Fig. 3, if MS3 chooses the one-hop path from RS3 to the MR-BS, it achieves the shortest path but increases the bandwidth load of RS3. Coversely, if MS3 chooses the two-hop path from RS2 to the MR-BS, the MS3 will transmit data via less bandwidth load path. Consequently, different selections yield different bandwidth loading on the WiMAX MMR network. In this work, the load balancing is chosen as an important impact factor for the path determination.

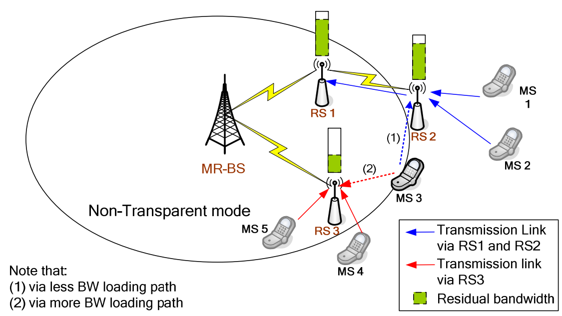


Fig. 3. RSs Load balancing in WiMAX MMR networks

### 3.2. Cost-based Competitive On-Line Routing

According to above analyses of impact factors, the cost-based Competitive On-Line (namely COL) routing approach is proposed herein to efficiently utilize limited wireless resource in WiMAX MMR network. The COL cost function has been studied in [13][14] for defining the competitive on-line access cost in terms of the residual bandwidth of nodes. The characteristic of the COL cost function is increased exponentially as the residual bandwidth decreases, rather than a linear function. In [15], Gawlick *et al.* proposed the Competitive On-Line routing algorithm for general networks. The COL approach sets the system cost as an exponential function of the residual bandwidth of system.

Thus, the cost of carrying a call on a node $\ell$ with occupancy $i$ can be expressed as

$$W_\ell(i) = \mu^{\frac{i}{C_\ell}}, \tag{4}$$

where $\mu$ denotes a selected constant parameter and $C_\ell$ represents the capacity of link $\ell$. A path is accepted as a candidate path if its cost is less than a threshold $\rho$, which is another chosen parameter. If there are more than one candidate paths, the path with the least path cost is selected for the connection. Allan and El-Yaniv [16] suggested setting $\rho$ to $\mu$. Meanwhile, Zhang *et al.* [17] indicated that if $\ell$, this is equivalent to setting the admission threshold to one and the cost of a node with occupancy $i$ to

$$W_\ell(i) = \mu^{\frac{i}{C_\ell}-1}. \tag{5}$$

Since $0 \le i \le C_\ell$, we have $0 \le W_\ell(i) \le 1$.

The link cost for class $k$ call, $p_k^\ell(i)$, are defined herein by

$$p_k^\ell(i) = \begin{cases} \sum_{j=i}^{i+b_k-1} \mu^{\frac{j}{C_\ell}-1} & \text{if } i + b_k \le C_\ell, \\ \infty & \text{otherwise.} \end{cases} \tag{6}$$

Since different traffic classes have different QoS requirements and reward parameters, in this paper, each class of traffic is associated with a call admission threshold.

After determining the carrying path cost, $p_k^\ell(i)$, the path selection is performed as below. If there are more than one candidate paths between the MS requesting the connection to the MR-BS, the least cost path will be chosen as the selected routing path. Furthermore, the procedure of path determination will be performed at a MS/RS when the MS/RS performs handoff to another target RS or the MR-BS.

In OFDMA, the transmission data rate (i.e., transmission quality) is dynamically adjusted with the AMC scheme. Thus, if there are several selected routing paths with the same least path cost, **an adaptive Max-Min AMC approach** is proposed to determine the optimal path, as detailed as follows.

Table III defines the AMC indexes for different OFDMA zones. The AMC index of link $j$ on a candidate path $i$ is denoted as $AMC_{i,j}$. The bottleneck link's AMC index of the path $i$ can be obtained by

$$AMC_i = \min_{\forall \text{link } j \in \text{path } i} \left\{ AMC_{i,j} \right\}, \tag{7}$$

Finally, if there are $I$ paths with the same least path cost, the optimal routing path, $R_{opt}$, is determined by

$$R_{opt} = \max_{\substack{\forall \text{path } \boldsymbol{i} \text{ is with} \\ \text{the least path cost}}} \left\{ \min_{\forall \text{link } j \in \text{path } \boldsymbol{i}} \left\{ AMC_{i,j} \right\} \right\}, \tag{8}$$

In summary, since the proposed adaptive COL cost-based approach with AMC scheme consider the residual bandwidth, path hop count, load balancing and AMC coding rate, the determined optimal routing path achieves highly reliable and AMC coding rate MMR routing result, the data transmission rate and real-time streaming can be achieved while satisfying the required QoS parameters.

TABLE III. AMC index table

| OFDMA Zone Level (from the nearest to the farthest) | Adaptive modulation and coding rate | AMC Index (*AMC*) |
|---|---|---|
| 1 | 64QAM | *5* |
| 2 | 16QAM | *4* |
| 3 | QPSK3/4 | *3* |
| 4 | QPSK1/2 | *2* |
| 5 | BPSK | *1* |

## 4. NUMERICAL RESULTS

This section evaluates the proposed routing approach by comparing various performance metrics: FRL, utilization and average end-to-end delay. The compared approaches include: the hop-based routing, RS-type routing, bandwidth-based routing and normalized dynamic weighting [18] approaches (NDWA). In addition, the performance metrics under different number of MSs (NDS) and various arrival rates of service flows are evaluated.

The evaluated IEEE 802.16j MMR network is demonstrated in Fig. 1, which consists of a MR-BS, several RSs and *NDS* MSs. The totally MR-BS bandwidth in WiMAX is 35Mbps. In evaluations, three classes of traffic are considered, including Unsolicited Grant Service (UGS), real-time Polling Service (rtPS) and non real-time Polling Service (nrtPS). The parameters of traffic model of three service classes are summarized from [19-21], as depicted as follows.

The UGS traffic of an MS is allocated when the MS is registered to the MR-BS. A Constant Bit Rate (CBR) of 64 Kbps is allocated to each UGS that is suitable for the VoIP application. The rtPS service is assumed to arrive at the WiMAX network to a Poisson distribution with arrival rate, $\lambda$, ranging from 2 to 12. The average holding time of the rtPS service is exponentially distributed and its mean is normalized to unity. Meanwhile, the rtPS service can be used for Video on Demand (VOD). Conversely, the nrtPS service is assumed to arrive based on a Pareto distribution with parameters of $\alpha\_on$, $\alpha\_off$ and $\beta$. Such an nrtPS can be used for the applications of HTTP and FTP. Several useful parameters for the simulations are given in Table IV.

TABLE IV. The simulation parameters

| Simulation parameters | Values |
|---|---|
| Number of MSs (NDS) | 10~70 |
| Network Size | 2000 m |
| BS bandwidth | 35 Mbps |
| Bandwidth for UGS (CBR) | 64 Kbps |
| Bandwidth for rtPS | 16 Kbps |
| Bandwidth for nrtPS | 6 Kbps |
| packet size | 1200 bytes |
| Arrival rate of Poisson distribution, $\lambda$ (rtPS) | 2~12 |
| Average holding time of Exponential distribution, $\mu$ (rtps) | 1 |
| Parameters of Pareto distribution, $\alpha\_on$, $\alpha\_off$ and $\beta$ (nrtps) | 1<br>1.5<br>1.1 |
| Simulation Time | 1100 s |

Fig. 4 demonstrates FRLs under various arrival rates ranging from 2 to 12. FRLs of all compared approaches increase as the arrival rate increases. The proposed COL approach yields the lowest FRL, but TYPE results in the highest FRL. The reason is that COL achieves load balancing and less hop-count per path. Conversely, in the TYPE approach MSs always select FRS firstly. As a result, they exhaust the bandwidth of FRS, and then cause more blocking and high FRL.

Fig. 5 shows the MR-BS utilization (UT) under various arrival rates ranging from 2 to 12. The results are similar to those in Fig. 4. The primary reason is that the proposed COL approach achieves low blocking probability and thus leads to the highest utilization.

In Fig. 6, we also consider the IEEE 802.16e topology that excludes any RSs within the MR-BS. Fig. 6 evaluates FRLs under various number of nodes (NDS) ranging from 10 to 70. We can see that the COL approach yields the lowest FRL but IEEE 802.16e leads to the highest FRL. The primary reason is that the IEEE 802.16e standard does not provide the coverage extension by using RSs.

## 5. CONCLUSIONS AND FUTURE WORKS

This paper proposed an adaptive path determination for IEEE 802.16j MMR networks. The proposed approach for the non-transparent mode with the distributed scheme use to improve the MR-BS utilization enhancement and reduce End-to-end path delay of WiMAX MMR networks. Numerical results show that COL achieves several advantages. First, it increases the network utilization and thus minimizes FRL. Second, the COL approach reduces the average End-to-End path delay of rtPS and nrtPS service flows. Finally, numerical results demonstrate that the proposed approach significantly outperforms IEEE 802.16e and other approaches in FRL and delay under various NDS and arrival rates.

Many metrics of selecting the optimal path of the IEEE 802.16j MMR networks require consideration. For example, spatial reuse and interference issue become more important. As a result, we plan to investigate the joint design of path selection method in the near future.

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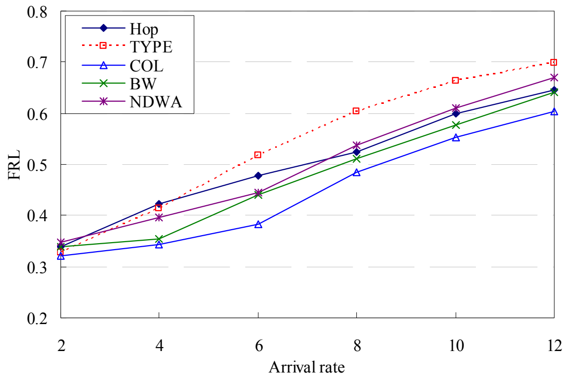


Fig. 4. FRL of different approaches under various arrival rates

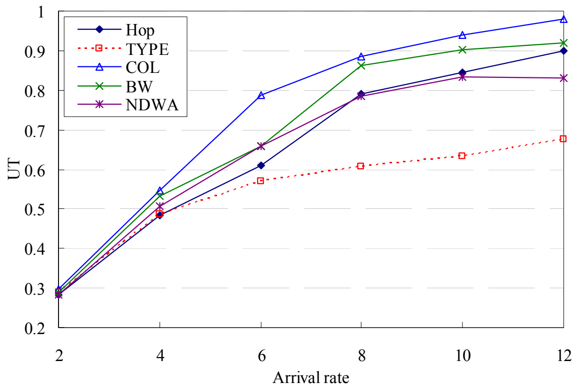


Fig. 5. Utilization (UT) of different approaches under various arrival rates

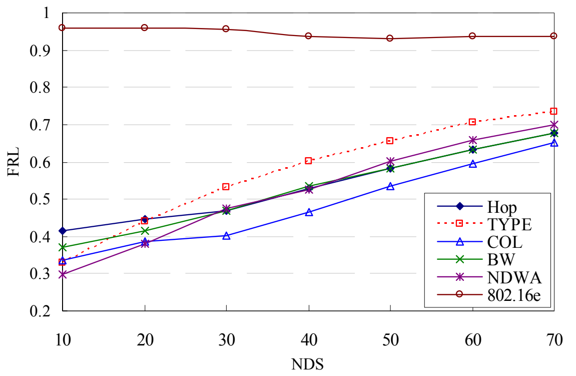


Fig. 6. FRL of different approaches under various numbers of nodes