

A Relay Station Deployment with Particular K-means Strategy for Multi-hop Relay Network Systems

Jau-Yang Chang¹ and Yun-Wei Chen²

Department of Computer Science and Information Engineering

National Formosa University

Hu-Wei, Yun-Lin, Taiwan

jychang@nfu.edu.tw¹

f88026679@yahoo.com.tw²

ABSTRACT

Multi-hop relay network systems allow users to communicate with a base station via a relay station, such as WiMAX 802.16j and Long Term Evolution (LTE)-Advanced. The overall coverage for the systems can be increased apparently and the throughput for the users will be enhanced by deploying suitable relay stations in such network systems. Considering a trade-off among the network throughput, the deployment budget, and the overall coverage, efficient relay station deployment strategies and corresponding algorithms must be developed and designed. This paper proposes a novel relay station placement strategy for the multi-hop relay network systems to enhance the overall coverage and maintain the network throughput at an acceptable level. We adopt the clustering concepts to select the better locations of relay stations from candidate positions. Simulation results show that the coverage for the systems and the throughput for the users can be increased by employing our proposed strategy in multi-hop relay network systems.

Keywords: clustering, coverage, deployment, multi-hop relay network, relay station, throughput

I. INTRODUCTION

Recently, multi-hop relay network techniques have been actively studied and considered in the standardization process of next-generation mobile communication systems, such as third generation partnership project long-term evolution (3GPP LTE) and IEEE 802.16 broadband wireless access systems, also refereed as WiMAX (worldwide interoperability of microwave access) standards. A multi-hop relay network specifies a system for combined fixed and mobile broadband wireless access environments [1], [2]. In such systems, the mobile stations (MSs) or fixed subscribe stations (SSs) can communicate to the base station (BS) directly, or via a relay station (RS). For the users, it is better to enhance the transmission throughput when using the systems. For the operators, it is better to increase the coverage of the systems.

The advantages of deploying RSs are as follows: (1) It is cheaper than BS. (2) Increasing the coverage of the system. (3) Enhancing the throughput for users. (4) Reducing the power consumption and path loss because the distance between a pair of communicating stations is shortened. Figure 1 shows an

example of the multi-hop relay network systems. The SSs and MSs are around the environment, they connect to the BS directly or via an RS. Additionally, several RSs are deployed in the systems. They connect between the users and the BS. The locations of RSs depend on the realistic environment such as the shadow of the building, valley between the buildings, and the coverage extension at the cell edges. Clearly, it should make a trade-off between throughput and the budget in the deployment problem. Consequently, the RS placement schemes are deeply researched in multi-hop relay network systems. The locations of RSs will directly affect the quality of service (QoS) for the users. To provide reasonable network throughput and to maintain the cost within the deployment budget, efficient RS deployment schemes must be developed in multi-hop relay network systems.

Several researches on the relay issues have been conducted in multi-hop relay network systems. In [4], the authors purpose a greedy heuristic relay station placement strategy (GHRSP) and give a sub-optimal solution to deploy RSs. Meanwhile, the authors also proof that the RS deployment problem is NP-hard. In [5], the authors also use the above concept to deploy RSs in 4G environment. In [6], the authors formulate the deployment problem as an Integer Linear Programming (ILP) model, and they propose a two-stage strategy to deploy BSs and RSs in a given geographic area. In [7], in order to obtain the high throughput, seamless intra-cell handoff among RSs, fault tolerances, and robustness in wireless fading channel, the authors purpose a dual-relay architecture which the user connects to the two different RSs at the same time. Previous schemes described above only take into account the problem in the deployment of RSs and emphasize the network throughput enhancement by deploying RSs. However, these schemes ignore the discussion between the deployment budget and the coverage ratio. Additionally, the assumption of candidate sites for RSs must be practical and reasonable. Due to the terrain constraints, it is evident that not all of the locations in the geographic area can be deployed the RSs.

Motivated by the above discussion, we propose a novel relay station deployment strategy in this paper to deploy RSs from the candidate positions by using a uniform cluster concept. In order to make an ideal clusters distribution for the demand nodes (DNs), we calculate the average distances between the DNs for deploying the appropriate RSs. Based on the different candidate positions, the proposed scheme makes an adaptive decision for deploying RSs. The favorable network throughput

and coverage ratio are obtained by balancing the network load among the clusters. Thus, our proposed deployment scheme has the ability to provide more efficient deployment in different candidate positions. We discuss and analyze the network throughput, the coverage ratio of DNs, and the deployment budget in this paper. The main benefits of proposed scheme are that the appropriate throughput and coverage ratio can be obtained by balancing the network load among the RSs. The reasonable QoS guarantees for the DNs can be provided and suitable deployment budget can be carried out in multi-hop relay network systems.

The rest of this paper is organized as follows. The system model is presented in section II. In section III, we illustrate the proposed strategy in detail. In section IV, we show the comparative evaluation results of the proposed strategy through the simulations. Finally, some conclusions are given in section V.

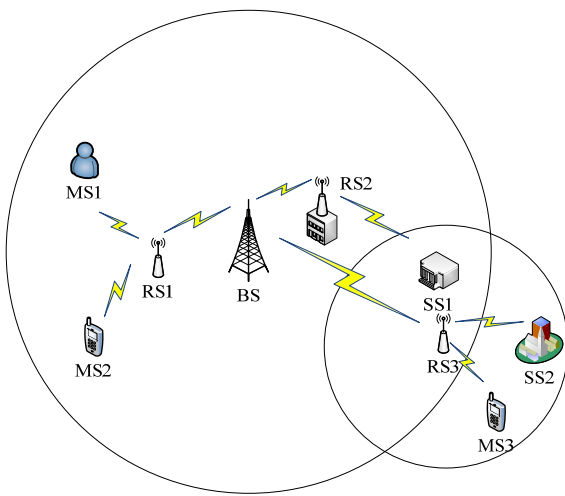


Figure 1. Relay Network Structure.

II. SYSTEM MODEL

In this paper, we consider a geographic area for deploying the RS positions (RPs) with a multi-hop relay network system. There are some candidate positions for the deployment RSs in this geographic area. Additionally, a large amount of DNs are located within the environment, and all of the DNs have a quantity of traffic demand to transmit. The multi-hop relay network systems allow one or more RSs to be deployed in order to extend the coverage of the BS and to enhance the overall capacity. In the environment, all of the data transmissions from the DNs are regard the BS as the final destination. The BS is connected to the wired backhaul and it is equipped with sufficient intelligence to deal with all the routing and connection requests in the environment. Thus, all of the RSs are just responsible for relaying data between the BS and the DNs, so it's unnecessary for them to connect to the wired backhaul. According to Figure 1, an RS can be set up on the roof of a building. For this reason, the RS has sufficient power

to transmit the signal. Since the BS is connected to a mobile switching center (MSC) and acts as a gateway from the wireless network to existing wired networks, the overall planning between the DNs and the BS and the transmission behaviors for multiple DNs should be considered simultaneously.

A multi-hop relay network system uses an adaptive modulation coding scheme (MCS) to allocate the data transmission rates for different channel condition. The received SNR is separated into several non-overlapping zones. The above statements can be shown in TABLE I and Figure 2 [8], [9]. If the distance between the two communication nodes is changed, the received signal noise to ratio (SNR) and data rate will be also changed. In other words, when the SNR decreases at the receiver, the sender will adopt a lower transmission mode to transmit by using a lower data rate. Oppositely, the sender will change the transmission mode to a higher order modulation in case the SNR gets better. Hence, it is an important factor for the distance between two nodes.

TABLE I. TRANSMISSION MODEL

| Modulation | Coding Rate | Receiver SNR (dB) | Data Rate (Mbps) | Distance (km) |
|------------|-------------|-------------------|------------------|---------------|
| BPSK | 1/2 | 3.0 | 1.269 | 3.2 |
| QPSK | 1/2 | 6.0 | 2.538 | 2.7 |
| QPSK | 3/4 | 8.5 | 3.816 | 2.5 |
| 16-QAM | 1/2 | 11.5 | 5.085 | 1.9 |
| 16-QAM | 3/4 | 15.0 | 7.623 | 1.7 |
| 64-QAM | 2/3 | 19.0 | 10.161 | 1.3 |
| 64-QAM | 3/4 | 21.0 | 11.439 | 1.2 |

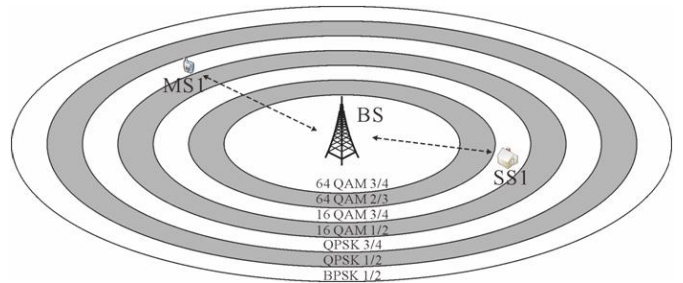


Figure 2. Seven Modulation Coding Scheme.

The end-to-end capacity can be defined as the throughput between the two communicating nodes [6]. If T_{BD} is the throughput from a BS to a DN, then it can be represented by

$$T_{BD} = \left(\frac{1}{D_{BR}} + \frac{1}{D_{RD}} \right)^{-1} = \frac{D_{BR} \times D_{RD}}{D_{BR} + D_{RD}}, \quad (1)$$

where D_{BR} is the data rate between a BS and an RS, and D_{RD} is the data rate between an RS and a DN.

In fact, there are probably many DNs in an environment, so an RS need to service several DNs at a time. If there are a large

amount of DNs that connect to the same RS, the overall capacity must be decreased seriously. So, we must not only extend the overall coverage, but also the network load should be taken into consideration for the multi-hop relay network. Suitable placements for RSs and DNs become important issues in both IEEE 802.16j and LTE-Advanced systems.

III. RELAY STATION DEPLOYMENT WITH PARTICULAR K-MEANS STRATEGY

In this section, we propose the Particular K-means Strategy (PKMS) to decide the locations of RS by using the clustering concept. Actually, when using the clustering based strategies, the DNs in the environment can be clustered uniformly before they connect to the RSs. For this reason, the overall coverage and total throughput for the DNs could be increased apparently.

PKMS is referred to general K-means clustering approach. In general K-means, the K will be determined in the beginning and generated K initial clustered heads (CHs) based on the average central point. All of the members in the environment will select one of the most nearest CHs to connect, becoming the new member of the selected cluster respectively. Then it forms K clusters in the environment. The next step is to find the new CH for each cluster. Hence the members with the same cluster will be recalculated their central point. In other words, the central point is the new CH of the cluster. After all of the new CHs are generated, each member in the environment will find one of the nearest new CHs to connect once again. That is to say, we just repeat to find the new CHs until all of them are unchangeable. We define the parameters and the functions in TABLE II, including the name, definition and explanation.

We apply the concept of K-means clustering to the environment and modify it to PKMS. The amount of clusters K is changed to K+1. For example, if the K+1 is seven, then it will generate seven clusters, and then delete the one which has the minimal distance to BS.

TABLE II. SUMMARY OF NOTATION

| Symbol | Definition |
|------------------|--|
| D | The set of DNs. $D = \{DN_d d = 1 \dots D \}$ |
| R | The set of RPs. $R = \{RP_r r = 1 \dots R \}$ |
| K | The set of RS (Budget). $K = \{RS_k k = 1 \dots K \}$ |
| SC | The set of clusters. $SC = \{C_k k = 1 \dots (K +1)\}$ |
| SCH | The set of clustered heads. $SCH = \{CH_k k = 1 \dots (K +1)\}$ |
| $DNCT$ | The connective set of DN. $DNCT = \{DN_CNT_d d = 1 \dots D \}$ |
| $dis(A, B)$ | The distance between node A and node B. |
| tmp_ctr_pt | The temporary central point. |
| tmp_ctr_rds | The temporary central radius. |
| $init_ctr_pt$ | The initial central point. |
| $init_ctr_rds$ | The initial central radius. |
| DN_count1 | The statistic of round. |

The corresponding algorithm is represented in TABLE III. In line 3-6, the positions for every DN and their distances to the BS are summarized and stored in tmp_ctr_pt and tmp_ctr_rds . On the basis of the two parameters, the initial central point

$init_ctr_pt$ and the initial central radius $init_ctr_rds$ can be represented as

$$init_ctr_pt = \frac{\sum_{d=1}^{|D|} X_{DN_d}}{|D|}, \quad (2)$$

$$init_ctr_rds = \frac{\sum_{d=1}^{|D|} dis(BS, DN_d)}{|D|}, \quad (3)$$

where X_{DN_d} is the coordinate of DN_d . Next, the initial CHs (X_{CH_k}, Y_{CH_k}) in SCH will be placed to the locations according to the following two formulas:

$$X_{CH_k} = X_{init_ctr_pt} + init_ctr_rds \times \cos\left(\frac{2\pi}{|K|+1} \times k\right), \quad (4)$$

$$Y_{CH_k} = Y_{init_ctr_pt} + init_ctr_rds \times \sin\left(\frac{2\pi}{|K|+1} \times k\right). \quad (5)$$

In line 13-30, it is a loop to implement the group classification for the DNs. So DN_CNT is assigned to record the classified status for the DNs in line 17, and the classified processing can be expressed by

$$C_k = \{DN_CNT_d: \text{with minimal } dis(DN_d, CH_k)\}, \quad (6)$$

In line 20-29, the new CH for each cluster can be calculated by

$$CH_k = \frac{1}{|C_k|} \sum X_{DN_d}, \quad \forall X_{DN_d} \in C_k, \quad (7)$$

where $|C_k|$ is the number of DNs in cluster k .

In case there is any CH which is changed, the same processing will be executed again until all of the CHs are fixed.

In line 31-35, the CH with the minimal distance to the BS will be deleted, and the DNs which are belonged to the deleted cluster should connect to the other nearest RS or the BS. For these available CHs in SCH , it will be respectively replaced by its nearest RP, and these RPs are the final locations to deploy RS.

Actually, the BS is also a node which the DNs can select. For instance, if the budget of RS $|K|$ is six, the actual number which the DNs can select is seven, inclusive of the BS. For the reason of fairness and actuality, the amount of clusters is modified to $|K|+1$.

TABLE III. THE ALGORITHM OF PKMS

| |
|---|
| 1. Input : D, R |
| 2. Initialization : $ K , DN_count1 = 0$; |
| 3. for $d = 1$ to $ D $ |
| 4. $tmp_ctr_pt \leftarrow tmp_ctr_pt + DN_d$; |
| 5. $tmp_ctr_rds \leftarrow tmp_ctr_rds + dis(DN_d, BS)$; |
| 6. end for |

```

7.  $init\_ctr\_pt \leftarrow tmp\_ctr\_pt / |D|$ ; //calculate the initial central point
8.  $init\_ctr\_rds \leftarrow tmp\_ctr\_rds / |D|$ ; //calculate the initial central radius
9. foreach  $CH_k$  in  $SCH$  //determine every cluster head
10.  $X_{CH_k} = X_{init\_ctr\_pt} + init\_ctr\_rds \times \cos\left(\frac{2\pi}{|K|+1} \times k\right)$ ; //x-axis of  $CH_k$ 
11.  $Y_{CH_k} = Y_{init\_ctr\_pt} + init\_ctr\_rds \times \sin\left(\frac{2\pi}{|K|+1} \times k\right)$ ; //y-axis of  $CH_k$ 
12. end foreach
13. do
14. for  $d = 1$  to  $|D|$ 
15.   for  $k = 1$  to  $|K|+1$ 
16.     if  $dis(DN_d, CH_k)$  is minimal
17.        $DN\_CNT_d \leftarrow C_k$ ; // DN connects to the nearest cluster.
18.     end for
19.   end for
20.   for  $k = 1$  to  $|K|+1$  //calculate each  $CH_k$  in cluster  $k$ .
21.      $DN\_count1 \leftarrow 0, tmp\_ctr\_pt \leftarrow empty$ ;
22.     for  $d = 1$  to  $|D|$ 
23.       if  $DN\_CNT_d$  is  $C_k$ 
24.          $tmp\_ctr\_pt \leftarrow tmp\_ctr\_pt + DN_d$ ;
25.          $DN\_count1 \leftarrow DN\_count1 + 1$ ;
26.       end if
27.     end for
28.      $CH_k \leftarrow tmp\_ctr\_pt / DN\_count1$ ;
29.   end for
30. until all of CH are unchangeable
31. foreach  $CH_k$  in  $SCH$ 
32.   if  $dis(BS, CH_k)$  is minimal
33.     delete  $CH_k$ ; //delete the CH with the nearest distance to the BS.
34.   end if
35. end foreach
36. for  $k = 1$  to  $|K|+1$ 
37.   for  $r = 1$  to  $|R|$ 
38.     if  $dis(RP_r, CH_k)$  is minimal and  $CH_k$  is available
39.        $CH_k \leftarrow RP_r$ ; //select a nearest RP to replace CH.
40.     end if
41.   end for
42. end for
43.  $K \leftarrow SCH$ ;
44. Output : $K$ 
    
```

The deployment of RSs is based on the objective function as follows:

$$Max. (\sum_{d=1}^{|D|} TD_d) \times CR, \quad (8)$$

where CR is the overall coverage and TD_d is the throughput of DN_d .

IV. PERFORMANCE ANALYSIS

We design a simulation model to evaluate the performance for our proposed scheme. We compare our strategies with GHRSP [4] and coverage based strategy (CBS). The coverage for each RP is defined as the amount of DNs which is inside the RP's coverage. In CBS, the coverage for each RPs will be determined at first. And then the RP with the highest coverage will be chosen to deploy an RS, because the selected RP can cover the most DNs in the environment. Hence, the DNs inside the RP's coverage will connect to the RS. The remaining DNs and RPs will repeatedly implement the same processing until the amount of RS is equal to $|K|$.

To prove that our proposed scheme is promising, we design a visual interface simulator by using C# and implement several existing schemes for fair comparison. The simulation

follows the transparent relay frame structure. The following are the assumptions and conditions for our simulation.

- (1) The Simulation environment is a square area with the size of $8 \text{ km} \times 8 \text{ km}$. The environment involves three entities: BS, RS, and DN.
- (2) The BS is located at the center of the environment.
- (3) All of the DNs are randomly distributed in the environment and the amount of DNs is 1000.
- (4) All of the RPs are also randomly distributed in the environment.
- (5) The coverage radius of the BS is 3.2 km, and the coverage radius of the RS is 1.9 km. The interference threshold for the RS is 1km.
- (6) Each RS will directly connect to the BS while each DN can directly connect to the BS or via an RS.
- (7) The traffic demand for each DN is uniformly distributed between 1 Mbps and 10 Mbps.
- (8) The deployment cost for an RS is 1 unit. The $|K|$ is defined as the RS deployment budget.
- (9) The data transmission rate between the DN and the RS are calculated based on the distance and coding rate as shown in Table I.

In order to prove that our proposed scheme is well-designed, the deployment result for the different schemes is analyzed in detail by using the visual interface simulator. We design a scenario with 1000 DNs and 200 RPs. According to the scenario, we use GHRSP, CBS, and PKMS to evaluate the coverage ratio and throughput respectively. The coverage ratio of DNs is defined as the percentage of the total DNs actually being covered by the BSs and the RSs. The throughput is defined as the average data transmission rate between all of the covered DNs (CDNs) and the BS when the traffic demand for each CDN is satisfied. Figure 3 illustrates the deployment results, where BP stands for the position of the BS. SRP and URP is the abbreviation of selected RS position and unselected RS position respectively. UDN represents the uncovered DN. According to Figure 3, both the coverage and the throughput of our proposed PKMS are higher than that of the GHRSP and CBS. The reason for this result is that we balance the network load by using a uniform cluster algorithm. The coverage ratio of DNs is extended and the suitable deployment budget can be carried out in multi-hop relay network systems.

In the light of Figure 3, it is clear that the suitable deployment for the RSs is an important feature for the multi-hop relay network systems. We also evaluate the performance of our proposed scheme in detail. The performance measures obtained on the basis of two hundred simulation runs are plotted as functions of the average coverage ratio, the average throughput, and the deployment cost. Figure 4 shows the average coverage ratio when the deployment budget is 6 units. Based on the same deployment budget constraint, the proposed strategy achieves a higher average coverage ratio when the number of candidate positions of RSs varies from 100 to 500. In view of Fig. 4, the proposed scheme also shows the average coverage ratio that is approximately 5 % higher than that of the GHRSP and CBS when the number of candidate positions of RSs varies from 100 to 500. Figure 5 shows the average throughput of our proposed scheme is better

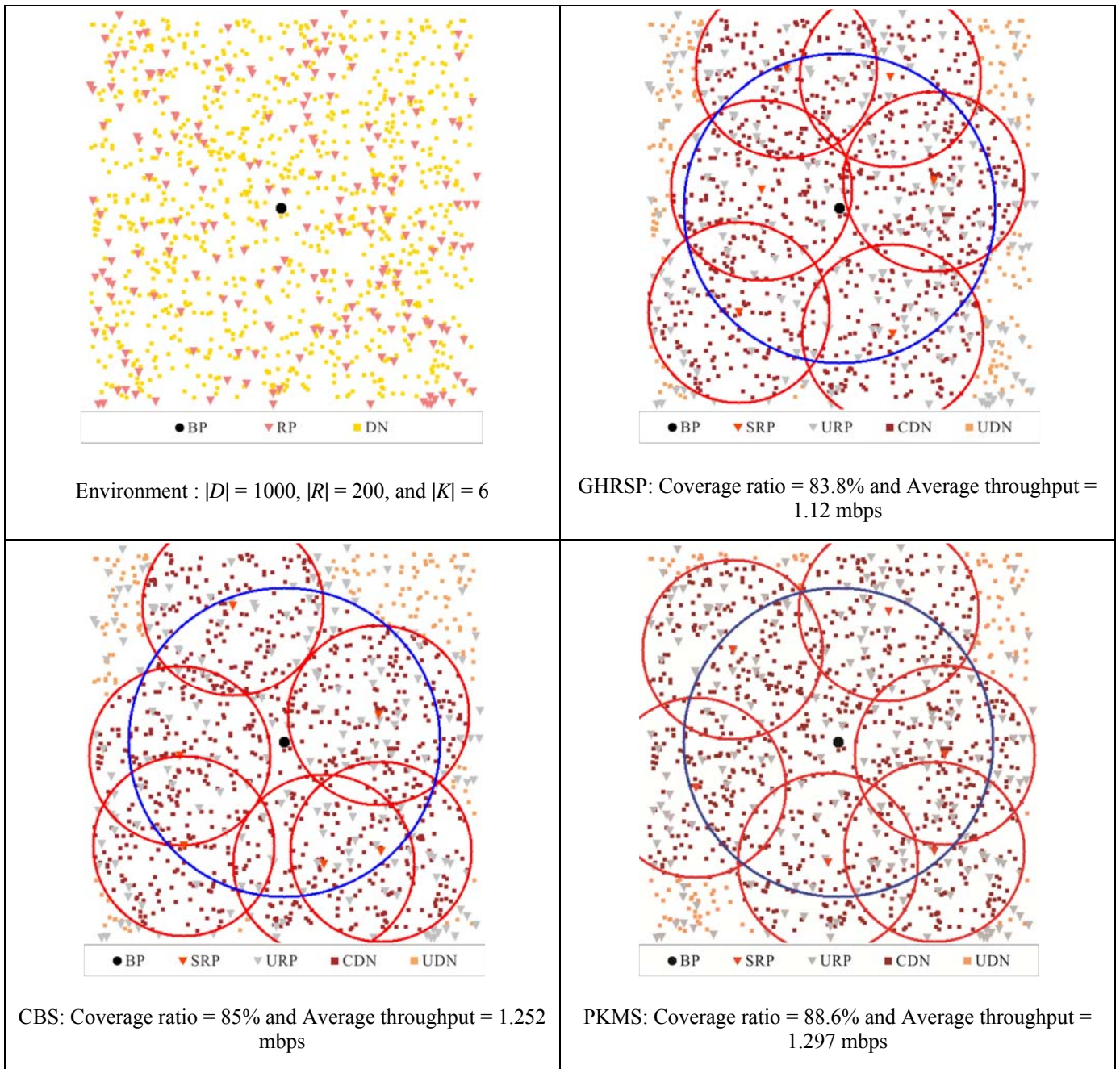


Figure 3. Deployment Results for $|K| = 6$.

than that of the CBS and GHRSP when the deployment budget is 6 units. The proposed scheme maintains the favorable average throughput when the number of candidate positions of RSs varies from 100 to 500. In CBS, the locations of RSs are determined by using the maximum coverage concepts such that the network can cover as many DNs as possible. However, It may result in too many DNs connect to the same RS. The RS will become the bottleneck link of traffic load and the data transmission will result in the packet queuing delay on the RS, and the data will be slowly transmitted. Hence, the reasonable network throughput is not obtained in CBS. The GHRSP scheme also results in unbalanced network load among the RSs

by considering the maximum data transmission rate between the RSs and the DNs. Hence, the average throughput of GHRSP scheme is close to that of the CBS. The DNs can obtain the better data transmission rate when the RSs are deployed in the suitable positions. The proposed scheme selects appropriate positions to deploy RSs from the candidate positions, and maintains the better throughput and coverage ratio. It results in the less packet queuing delay and significant data will be rapidly transmitted in multi-hop relay network systems.

Based on the coverage ratio constraint, Figure 6 shows the average deployment cost of the three schemes when the number of candidate positions of RSs is 200. The average deployment cost is defined as the minimal average deployment cost of RSs based on a certain coverage ratio constraint. The deployment cost of the three methods exhibit similar trends when the coverage ratio of DNs varies from 55 % to 90 %. However, the average deployment cost of GHRSP and CBS increase noticeably when the required coverage ratio increases. According to Figure 6, the curves indicate that the unsuitable RS placement methods results in higher deployment budget. However, the average deployment cost of our proposed scheme is lower than that of the GHRSP and CBS. This finding occurs because our proposed scheme employs the uniform clustering concepts and balances the network load. The suitable RS positions can be selected from the candidate positions. From the simulation results, it is clear that our proposed scheme not only achieves the appropriate performance level with respect to the average throughput and the coverage ratio, but also carries out the suitable deployment budget in multi-hop relay network systems.

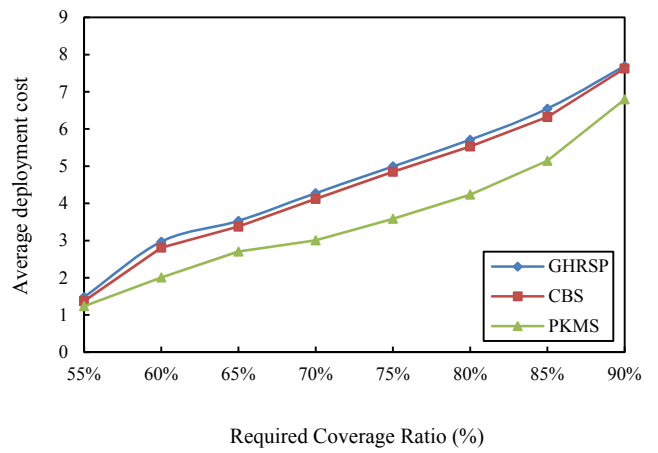


Figure 6. Average Deployment Cost

V. CONCLUSION

In this paper, an efficient cluster-based relay station placement strategy is proposed to determine the locations of RSs on the basis of the given DNs and RPs distribution, and RS deployment budget. We compared our proposed strategy with GHRSP and CBS. Simulation results show that the proposed strategy provides the appropriate performance in both coverage ratio and throughput for the MSs or SSs; meanwhile, the suitable number of RSs can be carried out. In our future study, the different scenarios such as more RPs or DNs will be studied. Besides, other aspect of strategies may be joined to get different results.

REFERENCES

- [1] Y. Yang, H. L. Hu, J. Xu, and G. Q. Mao, "Relay technologies for WiMAX and LTE-advanced mobile systems," *Communications Magazine, IEEE*, vol. 47, pp. 100–105, October 2009.
- [2] "Long Term Evolution Protocol Overviews," 2008.
- [3] "Harmonized Contribution on 802.16j (Mobile Multihop Relay) Usage Models," 2006.
- [4] H. C. Lu, W. J. Liao, and Lin. F. Y. -S, "Relay Station Placement Strategy in IEEE 802.16j WiMAX Networks," *Communications, IEEE Transactions*, vol. 59, pp. 151–158, January 2011.
- [5] Nivedita. M and Raja. G, "Efficient relay station placement strategy for broadband wireless networks - 4G," *Recent Trends In Information Technology (ICRTIT)*, pp. 282–286, April 2012.
- [6] H. C. Lu and W. J. Liao, "Joint Base Station and Relay Station Placement for IEEE 802.16j Networks," *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*, pp. 1–5, 2009.
- [7] B. Lin, P. H. Ho, L. L. Xie and X. Shen, "Relay Station Placement in IEEE 802.16j Dual-Relay MMR Networks," *Communications, 2008. ICC '08. IEEE International Conference*, pp. 3437–3441, May 2008.
- [8] "IEEE Standard for Local and Metropolitan Area Networks - Part 16: Air Interface for Broadband Wireless Access Systems," May 2009.
- [9] IEEE Std. 802.16j – 2009, IEEE Standard for Local and Metropolitan area networks, Part 16: Air Interface for Broadband Wireless Access Systems, Amendment for Multihop Relay Specification, May 2009.

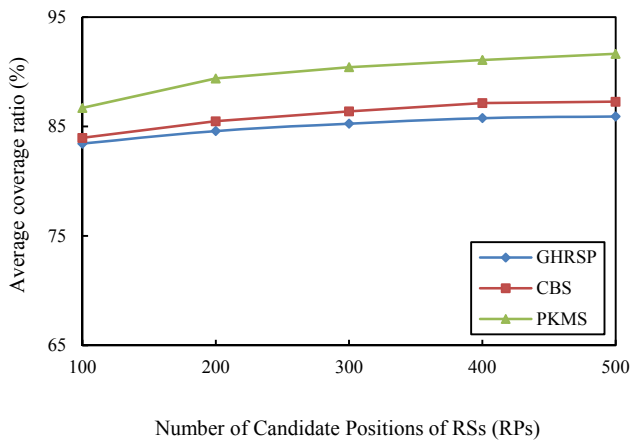


Figure 4. Average Coverage Ratio.

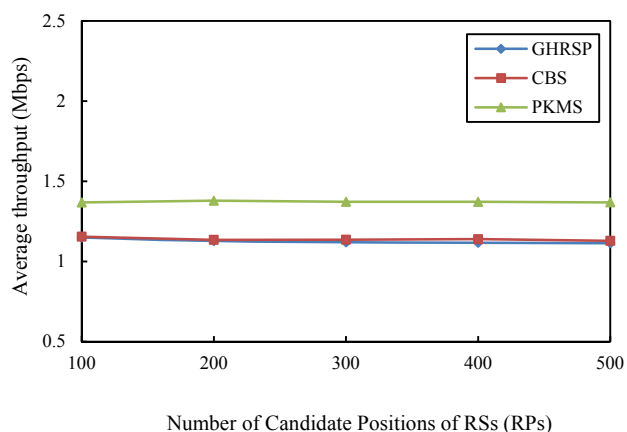


Figure 5. Average Throughput.