Analyses of QoS-based Relay Deployment in 4G LTE-A Wireless Mobile Relay Networks*

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

Abstract —In 4G cellular networks: LTE/LTE-Advanced and the mobile WiMAX network, some key impact factors degrade signal transmission quality and reduce wireless service coverage significantly. The specifications of LTE-Advanced and IEEE 802.16j thus propose a relay-based scheme, namely Mobile Multihop Relay (MMR) networks, to cooperate with the existing cellular network and to guarantee QoS for requests while not obviously increasing the Relay Station (RS) deployment cost. To efficiently deploy different types of RSs becomes a critical issue. Thus, this paper first analyzes the impact factors: transmission quality, deployment price, service coverage and RS overlap index, and then models the cost-effective issue of the RS deployment as an optimization problem. The paper proposes an Adaptive Cost-based RS Deployment (ACRD) approach to form a cost function in terms of all impact factors, and then solves the optimization problem by determining the RS deployment with the least network cost as the solution. Numerical results demonstrate that ACRD outperforms the compared approaches in network cost, transmission quality, RS deployment price, service coverage, and RS overlap index. ACRD deploys more RSs on the areas with high-density populations and thus increases transmission quality and guarantees the quality of service (QoS).

Keywords—*Mobile multihop relay, LTE-Advanced, QoS, RS deployment, adaptive cost function*

1. INTRODUCTION

The specifications of the 3GPP Long Term Evolution (LTE) [1] and the IEEE 802.16e mobile WiMAX [2] have been extensively developed and promoted to increase high data rate of packet services. However, signal fading, attenuation, and path loss resulted from some obstacles (e.g., skyscrapers, hills, narrow alleys, etc.) or caused by mobile nodes locating near the service coverage boundary and thus reducing transmission quality and data rate. Extended from the relaying technology of IEEE 802.16j [4], LTE-Advanced [3] specifies the relaying mechanism for reducing dead areas, extending the service coverage and improving transmission quality, while not increasing the network deployment cost significantly.

With the limited network resources and network deployment cost, how to efficiently utilize diverse-type RSs for improving network performance becomes as a critical challenge. Several studies [5][6][7][8][9][10] are proposed to deploy various-type RSs in MMR networks. In [6], based on the Manhattan-like environment, RSs are deployed to guarantee having the following two features: 1) Line-of-Sight (LOS) from RSs to the BS and 2) Non-LOS (Non-LOS) from a RS to other interfering RSs. Secondly, the reuse of radio-resources on different radio links is exploited to improve network capacity.

In [7], Yu *et al.* plan the locations of BSs and RSs in IEEE 802.16j by using a cost function. The cost-effective coverage extension issue has been studied in [8], in which [8] first analyzes the deployment cost, and then determines the optimal numbers of BSs and RSs in terms of various traffic parameters [8]. In [9], Ge *et al.* apply the MMR network to high-mobility transport systems, i.e., deploying an RS on transport systems, and then an MS can select an optimal RS to achieve high end-to-end capacity.

In [10], Lin *et al.* consider the issue of deploying a single RS in a network. In [11], Theodoros *et al.* consider both constraints of the Received Signal Strength Indicator (RSSI) and C/(I+N) (i.e., Carrier to Noise and Interference Ratio), and then shows the throughput under both the LOS and Non-LOS situations. In [14], Grenier *et al.* address the problem of efficiently planning mesh networks in the urban environment, in which they summarize that the key topics of the BS deployment include the analyses of coverage and connectivity.

However, most previous studies [6][7][8][10][11] of the relay node deployment approaches only consider the FRS and focus on increasing throughput by selecting the RS with high data rate. Furthermore, several studies [18][19] investigate the relay efficiency and the QoS-based flow management in LTE-Advanced and WiMAX MMR networks. Several studies [20][21][22] propose some relay selections for handoff connections.

Clearly, the wireless networking needs to achieve two objectives: 1) to guarantee the QoS of the request clients, and 2) to minimize the network cost and then to maximize the network reward (i.e., revenue). However, the QoS-based cost-reward network of mobile multi-hop relay is affected by several

* This research was supported in part by the National Science Council of Taiwan, ROC, under Grants MOST-104-2221-E-224-010, NSC-101-2221-E-224-022-MY3 and NSC-103-2221-E-252-008.

1. B.-J. Chang is with the department of Computer Science and Information Engineering, National Yunlin University of Science and Technology, Taiwan, ROC. (Corresponding author; phone: +886-5-5342601*4511; fax: +886-5-5312170; e-mail: changb@yuntech.edu.tw).

2. Y.-H. Liang is with the department of Multimedia Animation and Application, Nankai University of Technology, Taiwan, ROC. (E-mail: t136@nkut.edu.tw).

3. S.-S. Su is with the department of Computer Science and Information Engineering, Chaoyang University of Technology, Taiwan, ROC. (E-mail: s9527631@cyut.edu.tw).

important factors, e.g., the cost of deploying various-type RSs, the service coverage, etc. Thus, the motivation of this paper is to formulate the RS deployment issue as an optimization problem, and then an Adaptive Cost-based Relay Deployment approach is proposed to minimize the network cost.

The remainder of this paper is organized as follows. Section 2 details the proposed ACRD approach. Numerical results of the proposed approach and all compared approaches are presented in detail in Section 3. Finally, conclusions are given in Section 4.

2. Adaptive Cost-based RS Deployment Approach

This section first describes the motivations, and then details the proposed ACRD approach for the LTE-Advanced and the WiMAX MMR networks.

The MMR network specifies diverse types of RSs for providers to improve transmission quality and to extend service coverage while not increasing significant RS deployment cost. However, some critical impact factors: RS type, RS deployment price, RS service range, RS reliability, and transmission quality of RS channel state, significantly affect the RS deployment result. Thus, that motivates us to propose an adaptive RS deployment approach consisting of two phases: **1)** the impact factors analyses phase and **2)** the Adaptive Cost function RS Deployment phase. Some assumptions are listed below,

1. Assume that the self-backhauling relay operates with Type-I (or non-transparency) and outband mode is adopted, and every FRS has its own frequency spectrum [4].
2. FRSs only can be deployed within the coverage of the BS in order to increase transmission quality [4].
3. NRSs and MRSs are considered to randomly move around the network [4], and they can move outside the coverage of a BS/eNB.
4. Different-type RSs have different functionalities, and thus have different deployed prices.
5. The AMC scheme provided by the physical layer is considered, in which a tier is defined and assumed that the area within the same tier will adopt the same AMC coding scheme. The tier index is denoted by t, where $1 \le t \le T$, and $t = 1$ means the nearest tier from the MR-BS.

2.1 Phase 1. Different impact factors affecting the RSs deployment

In the MMR network, an adaptive efficient RS deployment approach is required to increase transmission quality while not increasing network cost. In [6][7][8][10][11][12][13][17], the studies have been shown that several factors: the RS deployment price [7][8], the service coverage [11][17], the signal quality [6][10][11], and the RS reliability [14], significantly affect the network cost. Based on the cost-effective criteria, we define some important impact factors as follows.

2.1.1 Transmission Quality Index (TQI)

LT-Advanced [1][3] and WiMAX [2][4] adopt the AMC scheme for mobile nodes to dynamically adjust the modulation coding scheme according to the interference (e.g., path loss, shadowing effect, signal attenuation, etc.) between the BS and the mobile node [2][4]. The key advantage of using AMC is to obtain the optimal capacity (i.e., data rate) according to the interference, e.g., wireless interference, path loss, shadow fading, etc. For example, Fig. 1 demonstrates that the inner tier has a higher SNR and then adopts 64 QAM AMC, but the outer tier only can use the BPSK scheme instead. An MS with the higher AMC (e.g., 64-QAM) yields a higher capacity (i.e., data rate) and higher transmission quality (i.e., SNR) than that of BPSK. Thus, TQI is formulated as

$$TQI = \sum_{t=1}^{T}\sum_{s=1}^{S}\left(N_s^t \cdot V^t\right), \quad (1)$$

where V^t denotes the transmission quality of RSs at tier t, t is the tier index, s is the RS type, T is the total number of tiers of the BS coverage, and S is the total number of RS types adopted in the MMR network. As a result, to maximize TQI is equivalent to guarantee QoS of connections and to achieve high data rate.

Additionally, in the MMR network, the physical coding scheme, e.g., the Orthogonal Frequency-Division Multiple Access (OFDMA) coding scheme [2][4][17]. Different FRSs deployed on the populated areas will adopt different frequency bands, different orthogonal frequency carriers, and different channelization codes. As a result, the wireless and communication interference can be minimized by using the OFCDM coding technology. Thus, a populated area deployed more FRSs improves TQI, and does not yield much interference, because LTE/WiMAX adopts the AMC and OFCDM technologies. That is, TQI does not affect the SCI (or SCI_P).

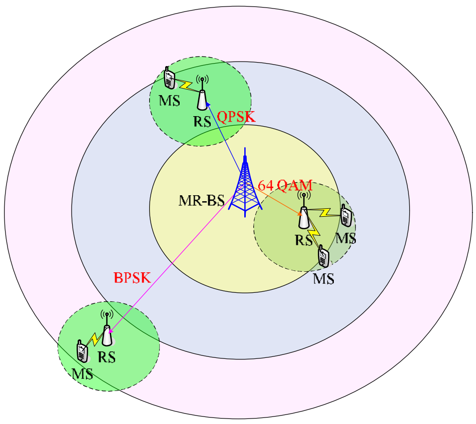

Fig. 1. Different RSs use different modulations and coding schemes

2.1.2 Price of the deployed RSs Index (PRI)

Different-type of RSs (Fixed RS, Nomadic RS, and Mobile RS) have different prices. This paper adopts the Price of the deployed RSs Index (PRI) as the total required price for the deployed RSs. As a result, PRI concerns the deployed RS types, rather than the position (or at which tier) of the deployed RS. The PRI is examined, which is defined as

$$PRI = \sum_{t=1}^{T}\sum_{s=1}^{S}\left(N_s^t \cdot C_s\right), \quad (2)$$

where C_s denotes the deployment price of type s RS and N_s^t denotes the number of type s RSs at tier t, where $1 \le s \le 3$;

$s=1$ means FRS ; $s=2$ means NRS; and $s=3$ means MRS. Lower PRI means it deploys less number of RSs and requires less RS deployment price.

2.1.3 Service Coverage Index (SCI and SCI_P)

The goal of a RS deployment algorithm is either to cover as wide as possible or to cover the coverage (area) where several connections (i.e., populations) exhibit to be carried. In the first case, with unlimited resources, the best case is to deploy all RSs over the entire coverage within the MR-BS coverage while not considering the distribution of populations, as demonstrated in Fig. 2. Thus, the main difference between SCI and SCI_P is SCI does not consider populations distributed in the coverage but SCI_P does. However, the actual network is difficult to satisfy these two cases, because the resources and cost are limited and the populations are not distributed averagely over the entire MR-BS coverage.

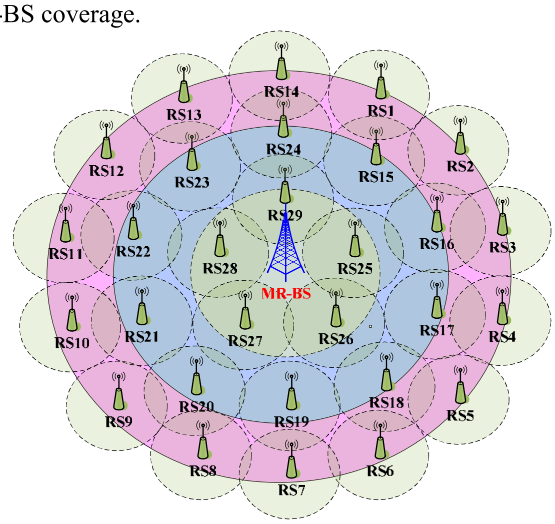

Fig. 2. The best case example of RS deployment in the MMR network with unlimited resources

Clearly, under the limited resources, a critical challenge facing a cost-effective RSs deployment exhibits in a mobile multihop LTE-Advanced/mobile WiMAX. Thus, this paper considers two cases of the population distributions among different tiers: the uniform distribution of a homogeneous distribution type (SCI) and the Non-Homogeneous Poisson Process, NHPP, (denoted by SCI_P). First, in the uniform distribution case, the population is uniformly distributed between the minimum and maximum wireless ranges, i.e., between 0 and R, where r is the wireless transmission range and $0 \le r \le R$. Second, in the NHPP case, the population is distributed among different tiers according to the population rate generalized function, $\lambda_t(\tau)$, with the expected value between the time interval $\tau_{i-1} < \tau \le \tau_i$ as,

$$\lambda^t_{\tau_{i-1},\tau_i} = \int_{\tau_{i-1}}^{\tau_i} \lambda^t(\tau) d\tau ,$$

and then the number of residents of tier r in the time interval $\tau_{i-1} < \tau \le \tau_i$, given as $N(\tau_i) - N(\tau_{i-1})$, where the probability function of NHPP is shown as

$$P[(N(\tau_i) - N(\tau_{i-1})) = k] = \frac{e^{-\lambda^t_{\tau_{i-1},\tau_i}} (\lambda^t_{\tau_{i-1},\tau_i})^k}{k!}, \qquad k = 0,1,2,...$$

The difference between these two cases is the population may be distributed unbalancedly; thus, an efficient RS deployment algorithm is needed to cover the unbalanced population. For fair processing and dynamic weighting for each impact factor, the SCI of a tier is normalized to the total area of the tier that can be covered by all FRSs.

Consequently, the indexes of SCI and SCI_P are defined as,

$$SCI = \frac{\sum_{t=1}^{T} \sum_{s=1}^{S} \left(N_s^t \cdot A_s \right)}{\sum_{t=1}^{T} \left(B_{s=1}^t \cdot A_{s=1} \right)}, \tag{3}$$

and

$$\sum_{s=1}^{S} \left(N_s^t \cdot A_s \right) \le B_{s=1}^t \cdot A_{s=1} , \tag{4}$$

where $B_{s=1}^t$ represents the maximum number of non-overlapping *FRS*s that can be deployed at tier t and $A_{s=1}$ is the service area of an *FRS*. Then, we define the SCI_P index by applying the population weight of tier t, $W_{pop}^{\lambda^t}$, to Eq. (3) as

$$SCI\_P = \frac{\sum_{t=1}^{T} \sum_{s=1}^{S} \left(N_s^t \cdot A_s \cdot W_{pop}^{\lambda^t} \right)}{\sum_{t=1}^{T} \left(B_{s=1}^t \cdot A_{s=1} \cdot W_{pop}^{\lambda^t} \right)}, \tag{5}$$

where W_{pop}^t represents that the population density of the deployed RS and $0 \le W_{pop}^{\lambda^t} \le 1$. Higher SCI or SCI_P is equivalent to yield more coverage.

2.1.4 RS Overlay Index (ROI)

In each tier of a MMR network, although the overlapping area of RSs offers an SS multiple upstream relay links to the MR-BS and increases network reliability, it brings several disadvantages: reducing the service coverage, increasing network cost, increasing number of deployed RSs, etc. As a result, the ROI is adopted, which is defined as shown in Eq. (6),

$$ROI = \frac{\sum_{t=1}^{t=T} E^t}{\sum_{t=1}^{T} \left(B_{s=1}^t \cdot A_{s=1} \right)}, \tag{6}$$

where E^t is the overlapping area at tier t, $B_{s=1}^t$ represents the maximum number of non-overlapping *FRS*s that can be deployed at tier t, and $A_{s=1}$ is the service area of an *FRS*. The ROI is formulated based on the ratio of the total RS overlapping area to the total area covered by FRSs. An approach yielding a lower ROI is equivalent to yielding a better performance and a lower network cost.

2.2 Phase 2. Adaptive Cost-based RS Deployment approach

Based on above analyses of important impact factors, we propose a cost-effective RS deployment approach, namely ACRD, to achieve several significant contributions:

(1) Formulating the cost-effective problem as an adaptive cost function in terms of all impact factors, in which dynamically weighting is adopted for various factors, and

(2) Dynamically deploying RSs in order to maximize transmission quality, service coverage, and network reliability while not to increase the network cost.

2.2.1 **Step 1**. Defining the Optimization Problem of the RS Deployment Issue

The objective equations and constraints for minimizing the network cost are built by the optimization problem.

Minimize

$$Min\left\{\sum_{t=1}^{T}\sum_{s=1}^{S}\left(N_s^t \cdot C_s\right)_p,\ \forall p \in P\right\}, \tag{7}$$

where P is the set of all possible RS deployment combinations.

Maximize

$$Max\left\{\sum_{t=1}^{T}\sum_{s=1}^{S}\left(N_s^t \cdot V^t\right)_p,\ \forall p \in P\right\}, \tag{8}$$

$$Max\left\{\left(\frac{\sum_{t=1}^{T}\sum_{s=1}^{S}\left(N_s^t \cdot A_s\right)}{\sum_{t=1}^{T}\left(B_{s=1}^t \cdot A_{s=1}\right)}\right)_p,\ \forall p \in P\right\},\ \text{or} \tag{9}$$

$$Max\left\{\left(\frac{\sum_{t=1}^{T}\sum_{s=1}^{S}\left(N_s^t \cdot A_s \cdot WP^t\right)}{\sum_{t=1}^{T}\left(B_{s=1}^t \cdot A_{s=1} \cdot WP^t\right)}\right)_p,\ \forall p \in P\right\},\ \text{and} \tag{10}$$

$$Max\left\{\left(1-\frac{\sum_{t=1}^{t=T}E^t}{\sum_{t=1}^{T}\left(B_{s=1}^t \cdot A_{s=1}\right)}\right)_p,\ \forall p \in P\right\}. \tag{11}$$

Subject to

$$CAP_W > \rho^1 > \rho^2 > \cdots > \rho^T > 0, \tag{12}$$

$$X_{FRS}^T > \cdots > X_{FRS}^2 > X_{FRS}^1 > 0,\ \text{and} \tag{13}$$

$$CAP_W - \left(\sum_{t=1}^{T}\rho^t \cdot N_s^t\right)_p \geq 0,\ \forall p \in P. \tag{14}$$

Note that Eq. (11) determines the RS non-overlapping ratio, in which the RS overlap index of a tier is formulated based on the ratio of the total RS overlapping area to the total area covered by FRSs.

2.2.2 **Step 2**. Transferring Impact Factors into Consistent Parameters

The objective of ***Step 2*** is to transfer every impact factor to a new metric, and all new metrics increase as the performance increasing. In ***Step 2***, we consider that a smaller value of a new metric is better. For instance, a higher TQI represents a better result. TQI is thus transferred to the new metric TQI^*, where $TQI^* = \frac{1}{TQI}$. After executing ***Step 2***, we have all consistent parameters (metrics), as indicated in Eq. (15),

$$\begin{cases} TQI^* = \dfrac{1}{TQI}, \\ PRI^* = \dfrac{PRI}{\sum_{t=1}^{T} X_{RS\_t} \cdot C_{s=1(FRS)}}, \\ SCI^* = \dfrac{1}{SCI}, \\ SCI\_P^* = \dfrac{1}{SCI\_P},\ and \\ ROI^* = ROI. \end{cases} \tag{15}$$

2.2.3 **Step 3**. Adaptive Weighting Scheme

Although the transferred parameters are consistent with the same feature, i.e., less the value of every parameter is equivalent to yield a better result, previous studies [6][8][9][10][15] suffer from static weighting [8] and unfair weighting [9][15] among various factors, and thus could not obtain the optimal results.

ACRD thus proposes an adaptive weighting for different parameters, which includes two operations: the 1) normalization and 2) dynamic weighting, as detailed below.

- Normalizing Operation:

  Since the value ranges of different parameters are different and to guarantee every parameter has the same value range, every parameter is normalized to TQI^*. Thus, we formulate their weights as

$$w_{TQI^*} : w_{PRI^*} : w_{SCI^*} : w_{ROI^*} = \frac{TQI^*}{TQI^*} : \frac{TQI^*}{PRI^*} : \frac{TQI^*}{SCI^*} : \frac{TQI^*}{ROI^*} \tag{16}$$

- Dynamic Weighting Operation:

  Dynamic computation of all parameters' weights are then determined by the principle of the proportional formula, $z_i = \frac{w_i}{w_T}$, where $w_T = \sum_{i=1}^{I} w_i$ and $\sum_{i=1}^{I} z_i = 1$, e.g.,

$$z_{TQI^*} = \frac{w_{TQI^*}}{w_T}. \tag{17}$$

Since each impact factor has been processed: the transformation of each consistent parameter and the adaptive weighting operations (including the normalization and dynamic weighting operations), the affection of each processed factor is thus fairly. In addition, the summation of all dynamic weights is equal to one, and thus the network cost can be expressed by the summation of the cost carried by all impact factors. That is, the network cost of a RS deployment combination p, C_p, can be obtained by

$$C_p = \left(z_{TQI^*} \cdot TQI^* + z_{PRI^*} \cdot PRI^* + z_{SCI^*} \cdot SCI^* + z_{ROI^*} \cdot ROI^*\right)_p,\ \forall p \in P, \tag{18}$$

where $z_{TQI^*} + z_{PRI^*} + z_{SCI^*} + z_{ROI^*} = 1$ and P is the set of all possible deployment combinations.

Finally, ACRD aims to minimize the network cost significantly affected by all impact factors. As a result, the optimal network cost C_{opt} is thus determined by

$$C_{opt} = \underset{\forall p \in P}{Min}\left\{C_p\right\}. \quad (19)$$

The network provider selects the deployment case that has the least cost as the optimal solution while achieving $Max(TQI)$, $Min(PRI)$, $Max(SCI)$, $Max(SCI\_P)$ and $Min(ROI)$.

For clear describing the determination of the network cost of a RS-deployment combination, an example is depicted below. We assume that the index results of a RS-deployment combination p are $TQI = 28$, $PRI = 6$, $SCI = 0.12$, and $ROI = 0.31$, which are determined from Eqs. (3)-(6). Then, transferring the impact factors into consistent parameters by Eq. (15) of Step 2, we have

$$\begin{cases} TQI^* = \dfrac{1}{28} = 0.0357, \\ PRI^* = \dfrac{6}{50} = 0.12, \\ SCI^* = \dfrac{1}{0.12} = 8.333, and \\ ROI^* = 0.31. \end{cases}$$

Next, Eq. (16) of Step 3 is executed to determine the adaptive weights for the consistent parameters as,

$$w_{TQI^*} : w_{PRI^*} : w_{SCI^*} : w_{ROI^*} = \frac{0.0357}{0.0357} : \frac{0.0357}{0.12} : \frac{0.0357}{8.333} : \frac{0.0357}{0.31},$$

i.e.,

$$w_{TQI^*} : w_{PRI^*} : w_{SCI^*} : w_{ROI^*} = 1 : 0.2975 : 0.0042 : 0.11516,$$

where,

$$w_T = \sum_{i=1}^{I} w_i = 1.41686.$$

Then, the dynamic weighting is executed by Eq. (17), i.e.,

$$z_{TQI^*} = \frac{w_{TQI^*}}{w_T} = \frac{1}{1.41686} = 0.7058,$$
$$z_{PRI^*} = 0.2100,$$
$$z_{SCI^*} = 0.0030, and$$
$$z_{ROI^*} = 0.0252.$$

The network cost of the deployment combination p, C_p, can be obtained by Eq. (18), i.e.,

$$C_p = (0.7085) \cdot 0.0357 + (0.21) \cdot 0.12 + (0.003) \cdot 8.333 + (0.0252) \cdot 0.31 = 0.0833.$$

3. Numerical Results

This section evaluates the performance of *ACRD* in several important metrics: *TQI, PRI, SCI, SCI_P* and *ROI*. The compared approaches include the RANDom deployment approach (*RAND*) [9], the Static average Weighting Approach (*SWA*) [11] and the Dynamic Weighting Approach (*DWA*) [15]. In *RAND*, various types of RSs are randomly deployed on the evaluated network and *RAND* neglects the population distribution. In *SWA*, RSs are statically deployed based on two constraints: the RSSI and C/(I+N) (i.e., Carrier to Noise and Interference Ratio). In *DWA*, RSs are deployed based on some constraints: path hop count, link rate, and the shared rate of a link; additionally, *DWA* dynamically re-deploys RSs when the constraints and the population distribution are changed.

The comparisons are evaluated by the GNU C++ programs coded and run on Linux. In evaluations, the models of network, population distribution and mobility are specified below. The network size is 2000*2000 (m^2) and the bandwidth capacity of a BS/eNB is supposed to 30-240 Mbps. In the channel model, the capacities of different types of RSs located at different tiers are varied according to the adaptive modulation coding scheme of different OFDMA zones [17]. The wireless ranges of a MR-BS and a FRS are set to 1 kilometer and 375 meters, respectively [8][16], in which the same type of RS is assumed with the same wireless range.

In the population distribution, the Fixed RSs are deployed based on the distributions of the uniform and the Non-Homogeneous Poisson Process (NHPP). In the mobility model, the Nomadic and Mobile RSs are moved based on the random-way point mobility model, in which the velocities of mobile relays and nodes are from 10 to 100 km/hr and the pause time is from 0 to 180 seconds according to the RS feature. For instance, the NRS is with long pause time and the MRS and MS are with a short pause time. Several simulation parameters are listed in Table III.

Table III. Experimental parameters

Simulation parameters	Values
Number of MSs (NDS)	10~70
Network Size	2000 * 2000 (m^2)
BS/eNB capacity	30~240 Mbps
MR-BS wireless radius	1000 m
FRS wireless radius (A_{FRS})	375 m
NRS wireless radius (A_{NRS})	300 m
MRS wireless radius (A_{MRS})	225 m

Figures 3-5 evaluate different approaches under various capacities of the BS/eNB, in which the performance of each approach improves as the BS capacity increases. In Fig. 3, ACRD yields the least network cost, but RAND yields the worst network cost. The reason is that ACRD achieves higher transmission quality and covers more service areas in MMR networks. Conversely, RAND randomly deploys FRSs and always deploys FRSs on the areas with fewer populations. RAND obviously wastes the bandwidth of the BS and the deployed FRSs, and then results in a higher network cost.

In Fig. 4, ACRD results in the highest TQI (or SNR) and RAND results in the worst one. In addition, DWA yields higher TQI than that of SWA. The reason is that ACRD deploys more FRSs to the areas with high population density, and thus significantly improves the transmission quality. However, RAND [6] and SWA [8] do not consider the population, so RAND and SWA yield the worst TQI.

Fig. 5 demonstrates that ACRD yields the highest Service Coverage Index (SCI) and Service Coverage Index with Population (SCI_P), but SWA yields the worst one. The reason is that ACRD considers the population distribution; however, the other approaches do not consider the factor. In addition, ACRD yields higher SCI_P than SCI, because ACRD considers the NHPP population distribution.

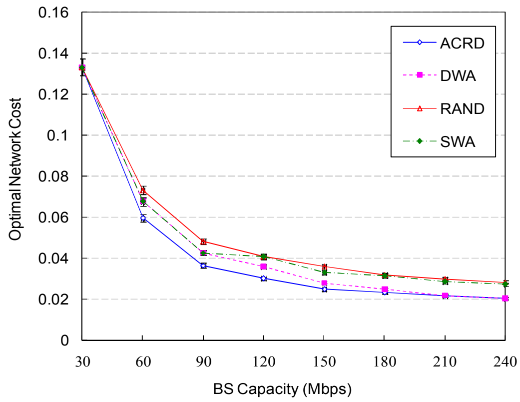

Fig. 3. The optimal network cost under various BS capacities

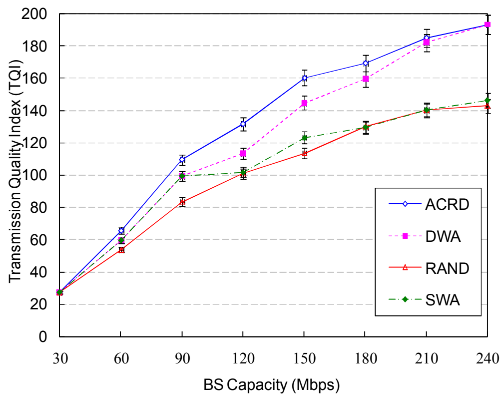

Fig. 4. TQI (or SNR) under various BS capacities

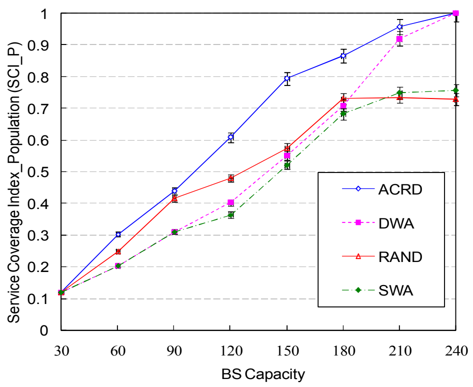

Fig. 5. SCI_P under various BS capacities

4. CONCLUSIONS

In 4G relay networks, an Adaptive Cost-based RS Deployment approach, namely ACRD, is proposed to achieve the supreme efficient deployment, while considering diverse impact factors: transmission quality, RS deployment price, service coverage, and RS overlap index. The main contribution of ACRD is to formulate an adaptive cost function in terms of all impact factors, and then to solve the optimization problem. Numerical results demonstrate that ACRD outperforms other approaches in network cost, transmission quality, RS deployment price and service coverage. Especially, in the transmission quality, ACRD yields 15% higher TQI than that of DWA, and 25% higher TQI than that of SWA. In the service coverage with considering population distribution, ACRD yields 30% higher SCI_P than that of DWA, and 35% higher SCI_P than that of SWA.

5. REFERENCES

[1] 3GPP TR V12.2.0, "LTE Physical Layer - General Description," 3GPP Rel. 12, 2013.

[2] "802.16-2009 - IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Broadband Wireless Access Systems," May 2009.

[3] 3GPP TR 36.912 V12.0.0, "Feasibility Study for Further Advancements for E-UTRA (LTE-Advanced)," *3GPP*, pp. 6-61, Mar. 2012.

[4] "IEEE 802.16j: Baseline Document for Draft Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems," July 2009.

[5] Y. Yang, H. Hu, J. Xu and G. Mao, "Relay Technologies for WiMAX and LTE-Advanced Mobile Systems," *IEEE Communications Magazine*, pp. 100-105, Oct. 2009.

[6] I.-K. Fu, W.-H. Sheen, and F.-C. Ren, "Deployment and radio resource reuse in IEEE 802.16j multi-hop relay network in Manhattan-like environment," *International Conference on Information, Communications & Signal Processing*, pp. 1-5, Dec. 2007.

[7] Y. Yu, S. Murphy, and L. Murphy, "Planning Base Station and Relay Station Locations in IEEE 802.16j Multi-Hop Relay Networks," *CCNC 2008*, pp. 922-926, Jan. 2008.

[8] S.-J. Kim, S.-Y. Kim, B.-B. Lee, S.-W. Ryu, H.-W. Lee, and C.-H. Cho, "Multi-Hop Relay Based Coverage Extension in the IEEE802.16j Based Mobile WiMAX Systems," *Fourth International Conference on Networked Computing and Advanced Information Management*, Vol. 1, pp. 516-522, Sep. 2008.

[9] Y. Ge, S. Wen, and Y.-H. Ang, "Analysis of Optimal Relay Selection in IEEE 802.16 Multihop Relay Networks," *IEEE Wireless Communications and Networking Conference*, pp. 1-6, Apr. 2009.

[10] B. Lin, P. Ho, L. Xie, and X. Shen, "Optimal relay station placement in IEEE 802.16j networks," *International Conference on Wireless Communications and Mobile Computing*, pp. 25-30, Aug. 2007.

[11] T. Theodoros and V. Kostantinos, "WiMax Network Planning and Systemys Performance Evaluation," *IEEE Wireless Communications and Networking Conference,* pp. 1948-1953, Mar. 2007.

[12] S.W. Peters and R.W. Heath, "The future of WiMAX: Multihop relaying with IEEE 802.16j," *IEEE Communications Magazine*, Vol. 47, Issue 1, pp. 104-111, Jan. 2009.

[13] V. Genc, S. Murphy, Y. Yu, and J. Murphy, "IEEE 802.16J relay-based wireless access networks: an overview," *IEEE Wireless Communications*, Vol. 15, Issue 5, pp. 56-63, Oct. 2008.

[14] E. Grenier and D. Humire, "Mesh network planning in urban environment," *ATDI*, pp. 1-35, 2006.

[15] J.S. Shin, R. Kumar, Y.S. Shin, and T.F. La Porta, **"**Multi-Hop Wireless Relay Networks of Mesh Clients," *IEEE WCNC*, pp. 2717-2722, 2008.

[16] O. Masato, C.X. Zhu, and V. Dorin, "Multihop Relay Extension for WiMAX Networks: Overview and Benefits of IEEE 802.16j Standard," *Fujitsu Scientific and Technical Journal*, Vol. 44, Issue 3, pp. 292-302, July 2008.

[17] Y.-K. R. Kwok and V. K.N. Lau, "Wireless Internet and Mobile Computing: Interoperability and Performance," *Wiley-IEEE Press*, 2007.

[18] R. Schoenen and A. Otyakmaz, "QoS and Flow Management for Future Multi-Hop Mobile Radio Networks," *IEEE VTC2010-Fall*, Oct. 2010.

[19] K. Loa, C.-C. Wu, S.-T. Sheu, Y. Yuan, M. Chion, D. Huo, and X. Ling, "IMT-advanced Relay Standards," *IEEE Communications Magazine*, vol. 48, issue 8, pp. 40-48, Aug. 2010.

[20] Y. Wang, G. Feng, and Y. Zhang, "Cost-efficient Deployment of Relays for LTE-Advanced Cellular Networks," *IEEE ICC 2011*, June 2011.

[21] T. Beniero, S. Redana, J. Hämäläinen, and B. Raaf, "Effect of Relaying on Coverage in 3GPP LTE-Advanced," *IEEE VTC-Spring 2009*.

[22] A. B. Saleh, Ö. Bulakci, S. Redana, B. Raaf and J. Hämäläinen, "Enhancing LTE-Advanced Relay Deployments via Biasing in Cell Selection and Handover Decision," *IEEE PIMRC 2010*, pp. 2277 - 2281.