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A Novel Fuzzy based Relay Node Deployment Scheme for Multi-hop Relay Network

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Abstract

In cellular communication, a multi-hop relay (MHR) network plays an important role by reducing the cost of deployment and extending the coverage area. To achieve high transmission rate and coverage, an efficient placement of relay nodes (RN) is needed in MHR network. In this paper, a suitable deployment scheme is proposed for the RNs to obtain high system performance. By using fuzzy logic, optimum deployment sites are selected for RNs, which results in better throughput and coverage. Simulation results shows that our proposed scheme gives a better throughput and coverage performance than the existing uniform clustering and joint base station and relay station placement (JBRP) scheme.

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Keywords: Coverage ratio (CR);Fuzzy logic;MHR network;Relay node(RN); Traffic ratio (TR);User node (UN).

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1. Introduction

MHR network have been proposed and considered in the wireless communication system such as Long term evolution (LTE) and worldwide interoperability for microwave access (WiMAX) IEEE 802.16j and IEEE 802.16m. In [1], MHR provide solutions to coverage extension by reducing the deployment as well as maintenance costs.

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Nomenclature

T_{eU}	throughput for indirect transmission
D_{UN}	data rate between MSC and UN.
T_{UN}	traffic demand of UN
DC_{eNB}	deployment cost of evolved NodeB (eNB)
DC_{RN}	deployment cost of RN
TDC	total deployment cost
CR	coverage ratio
TR	traffic ratio

In MHR network, UNs can be directly connected to an eNB or indirectly connected to eNB through RNs. All of the eNBs are directly connected to mobile switching center (MSC) which will interconnect both wired and wireless network. Thus it can accept more UNs results in coverage extension. Improper RN placement is a severe problem in cellular communication which increases the delay and reduces the throughput. Since many of the applications are time bounded, delay should be minimum [2]. By properly deploying RNs in the network the overall performance and the cell-edge throughput can be improved with minimum cost. RNs can be deployed and removed significantly faster than eNB but the placement of RNs depends on the factors like shadowing of the buildings and valleys [3]. So an effective deployment scheme for RNs is needed in MHR network. Fig. 1. shows an example of MHR model.

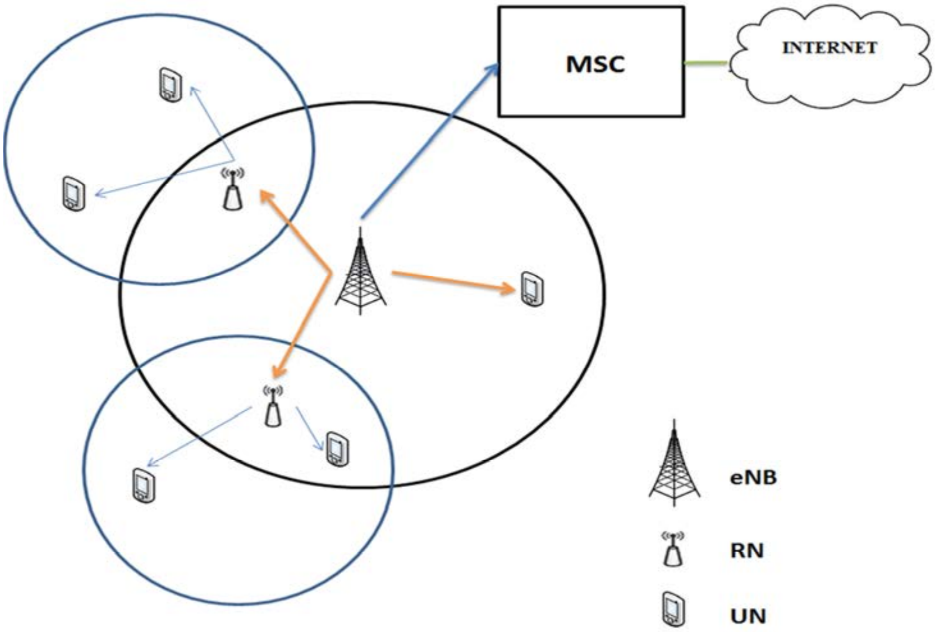

Fig. 1. MHR model

In [4], Cho et al. studied different handovers of RNs and propose a scheme where the RNs are placed in the boundary of two adjacent cells and hence the interruption delay due to handovers reduced. In [5], Yang et al. considered the RNs placement issues and deployed RNs in the cooperative communication mode so as to satisfy data rate requirements. A planning base station (BS) and relay station (RS) locations (PBRL) model is proposed by Yu et al. in [6] for MHR network, where they choose the locations for BS and RS from the candidate position. But there is no special consideration for throughput and coverage. In [7], Lu and Liao. proposed JBRP model with a two-stage algorithm, where in first stage they deploy eNBs in such a way that distance between UN and its nearest eNBs should be minimum and in second stage the deployment of RNs should cover as many as UN but results in an unbalanced system load between eNBs. Fuzzy based eNB deployment scheme is proposed by Jau-Yang Chang et al in [8]. The authors use fuzzy logic for eNB deployment and they use deploying factor (DF) for identifying RNs. In this work, we have uses the same fuzzy rule for RN selection.

The rest of this paper is organized as follows. In section 2, we discussed the proposed system model. Deployment scheme based on fuzzy logic and corresponding algorithm is described in section 3.Simulation scenario and results are showed in section 4. Finally, section 5 concludes the paper.

2. System Model

Adaptive modulation coding (AMC) method is widely used in MHR system for assigning various transmission rates to different users. The distance between two communication stations will change with time so the signal to noise ratio (SNR) also changes. The system will adopt a higher order modulation if the distance between stations is less. Similarly if distance is more between two nodes, then it will use lower order modulation for transmitting data. So, for choosing the link rate, we should consider the distance between the stations [9]. Table1 shows the AMC mode for different range of distances.

Table 1.AMC transmission mode [9]

Mode	Distance(Km)	Modulation	Coding rate	Data rate(Mbps)
1	3.2	BPSK	½	1.269
2	2.7	QPSK	½	2.538
3	2.5	QPSK	¾	3.816
4	1.9	16-QAM	½	5.085
5	1.7	16-QAM	¾	7.623
6	1.3	64-QAM	2/3	10.161
7	1.2	64-QAM	¾	11.439

Let U_{eR} be the data rate between eNB and RN, and U_{RU} be the data rate between RN and UN. Throughput for indirect transmission is given by [8]

$$T_{eu} = \frac{U_{eR} \cdot U_{RU}}{U_{eR} + U_{RU}} \tag{1}$$

The RN deployment is based on the following throughput function

$$\left[\left(\left(D_{UN_i} + T_{UN_i}\right) \cdot \alpha_i\right)\left(\sum_{i=1}^{N} \alpha_i\right)\right] \tag{2}$$

where D_{UN_i} is the data rate between the MSC and the ith UN, T_{UN_i} is the traffic demand of ith UN, and α_i is a binary value which is given by

$$\alpha_i = \begin{cases} 1, & \textit{if UN is assigned to a eNB or an RN} \\ 0, & \textit{Otherwise} \end{cases} \tag{3}$$

If there are t candidate locations of RNs in the coverage area of eNB, then the deployment budget constraint function is expressed as

$$DC_{eNB} + \sum_{j=1}^{t} DC_{RN} \cdot t \le TDC \tag{4}$$

where TDC be the total deployment cost, DC_{eNB} is the deployment cost of eNB, DC_{RN} is the deployment cost of RN.

3. Proposed Deployment Scheme

In order to increase the system throughput and network coverage an efficient RN deployment scheme is needed in MHR network. In this section we have proposed fuzzy logic based RN deployment scheme. Fuzzy logic is not precise and is from precision to imprecision. Since the real world is not precise hence fuzzy logic become very popular [10].

In [11], Jau-Yang Chang et al. have proposed a uniform clustering based eNB and RN placement scheme for MHR. This algorithm works in two phases namely eNB and RN positions selection phase and eNB and RN deployment phase. It has been showed that uniform clustering scheme offers better coverage and throughput performance over JBRP scheme.

The proposed algorithm is implemented in two phase namely RN position selection phase and RN deployment phase.

3.1 RN Positions Selection Phase

The CR and TR are the two input parameters for the fuzzy inference engine. Let CR_i and TR_i be the CR and TR for the i^{th} RN candidate position. The input fuzzy parameter CR_i is the ratio between the number of covered UNs (CUNs) to the number of UNs in the geographical area .TR_i is the traffic ratio between the average data transmission rate of the CUNs and the average traffic demand of the CUNs for the i^{th} candidate position of RN. If there are N number of UNs in the geographical area and NC_i be the number of CUN, then CR_i can be calculated by

$$CR_i = \frac{1}{N}\left(NC_i\right) \tag{5}$$

Let $A_{d,i}$ and $A_{t,i}$ be the average data transmission rate of the CUNs and the average traffic demand of the CUNs for the candidate position of i^{th} RN respectively. TR_i can be given by

$$TR_i = \frac{A_{d,i} - A_{t,i}}{\max\left\{A_{d,i}, A_{t,i}\right\}} \tag{6}$$

If the average traffic demand of the CUNs exceeds than the average data transmission rate of the CUNs then, the TR_i results a negative value which leads to a worst condition.

Low, Medium and High be the linguistic variables of CR_i for the candidate position of i^{th} RN with membership functions A_1^i , A_2^i and A_3^i respectively over [0, 0.2].

$$A_1^i(e) = \begin{cases} 1, & if\ e \le 0, \\ (0.1 - e)/0.1, & if\ 0 < e < 0.1, \\ 0, & if\ e \ge 0.1, \end{cases} \tag{7}$$

$$A_2^i(e) = \begin{cases} 0, & if\ e \le 0, \\ e/0.1, & if\ 0 < e < 0.08, \\ 1, & if\ 0.08 \le e < 0.12, \\ (0.2 - e)/0.1, & if\ 0.12 \le e < 0.2, \\ 0, & if\ e \ge 0.2, \end{cases} \tag{8}$$

$$A_3^i(e) = \begin{cases} 0, & if\ e \le 0.1, \\ (e - 0.1)/0.1, & if\ 0.1 < e < 0.2, \\ 1, & if\ e > 0.2, \end{cases} \tag{9}$$

Where $e \in [0, 1]$.Fig. 2. Shows the graphical representation of membership function CR.

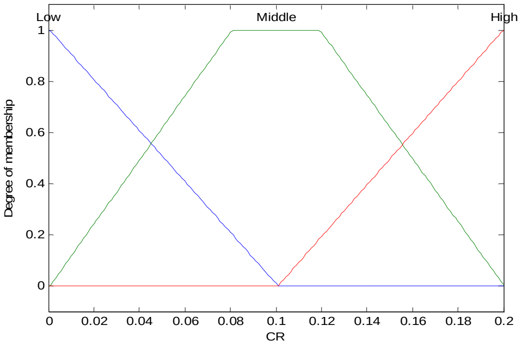

Fig. 2. Membership plot for CR

Similarly the membership functions of TR_i with linguistic variables Negative, Center and Positive are B_1^i , B_2^i and B_3^i respectively for the candidate position of i^{th} RN over the interval [-1,1].

$$B_1^i(f) = \begin{cases} 0, & if\ f \le -1, \\ -f, & if\ -1 < f < 0, \\ 1, & if\ f \ge 0, \end{cases} \tag{10}$$

$$B_2^i(f) = \begin{cases} 0, & if\ f \le -1, \\ (f+1), & if\ -1 < f < -0.2, \\ 1, & if\ -0.2 \le f < 0.2, \\ (1-f), & if\ 0.2 \le f < 1, \\ 0, & if\ f \ge 1, \end{cases} \tag{11}$$

$$B_3^i(f) = \begin{cases} 0, & if\ f \le 0, \\ f, & if\ 0 < f < 1, \\ 1, & if\ f \ge 1, \end{cases} \tag{12}$$

Where f∈ [-1, 1].Fig. 3. Shows the membership diagram of TR

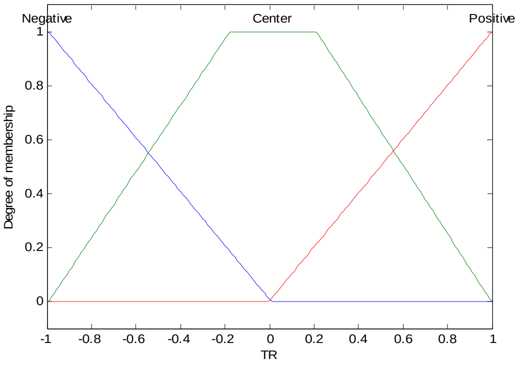

Fig. 3. Membership plot of TR

Deploying factor (DF) is the parameter that determines the RN positions from the candidate position of RNs. Small, Middle and Large are the linguistic variables for the output parameter DF_i with membership functions C_1^i, C_2^i and C_3^i respectively over [-1,1].Fig. 4. Shows membership diagram of DF.

$$C_1^i(g) = \begin{cases} 1, & if\ g \le -1, \\ -g, & if\ -1 < g < 0, \\ 0, & if\ g \ge 0, \end{cases} \tag{13}$$

$$C_2^i(g) = \begin{cases} 0, & if\ g \le -1, \\ (1+g), & if\ -1 < g < -0.2, \\ 1, & if\ -0.2 \le g < 0.2, \\ (1-g), & if\ 0 \le g < 1, \\ 0 & if\ g \ge 1, \end{cases} \tag{14}$$

$$C_3^i(g) = \begin{cases} 0, & if\ g \le 0, \\ g, & if\ 0 < g < 1, \\ 1, & if\ g \ge 1, \end{cases} \tag{15}$$

By using IF-THEN rules fuzzy logic can maps the input fuzzy set and output fuzzy set then find out the crisp output parameter DF. These fuzzy rules are described as follows:

1 : IF TR_i is Positive and CR_i is Low, THEN DF_i is Middle,
2 : IF TR_i is Center and CR_i is Low, THEN DF_i is Small,
3 : IF TR_i is Negative and CR_i is Low, THEN DF_i is Small,
4 : IF TR_i is Positive and CR_i is Medium, THEN DF_i is Large,
5 : IF TR_i is Center and CR_i is Medium, THEN DF_i is Middle,
6 : IF TR_i is Negative and CR_i is Medium, THEN DF_i is Small,
7 : IF TR_i is Positive and CR_i is High, THEN DF_i is Large,
8 : IF TR_i is Center and CR_i is High, THEN DF_i is Large,
9 : IF TR_i is Negative and CR_i is High, THEN DF_i is Middle.

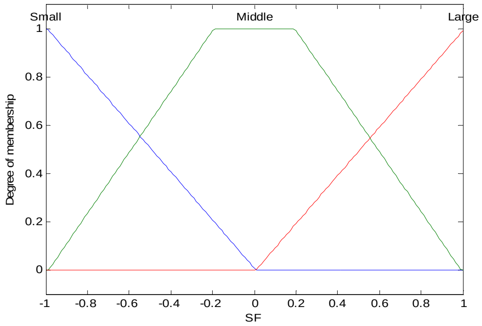

Fig. 4. Membership of DF

Fig. 5. Gives an example of the calculation procedure of DF with input as TR is equal to 0.6 and CR is equal to 0.161 by applying IF-THEN rules and three membership functions. The negative, center and positive membership grade for TR_i are 0, 0.4, 0.6 respectively. Similarly Low, Medium and High are the degrees of membership for CR_i are 0, 0.39, 0.61 respectively. Based on the nine rules, the nine different inference results are obtained and the final result will be the union of different results. By using centroid method [10] the crisp value DF_i can be found which is 0.143.

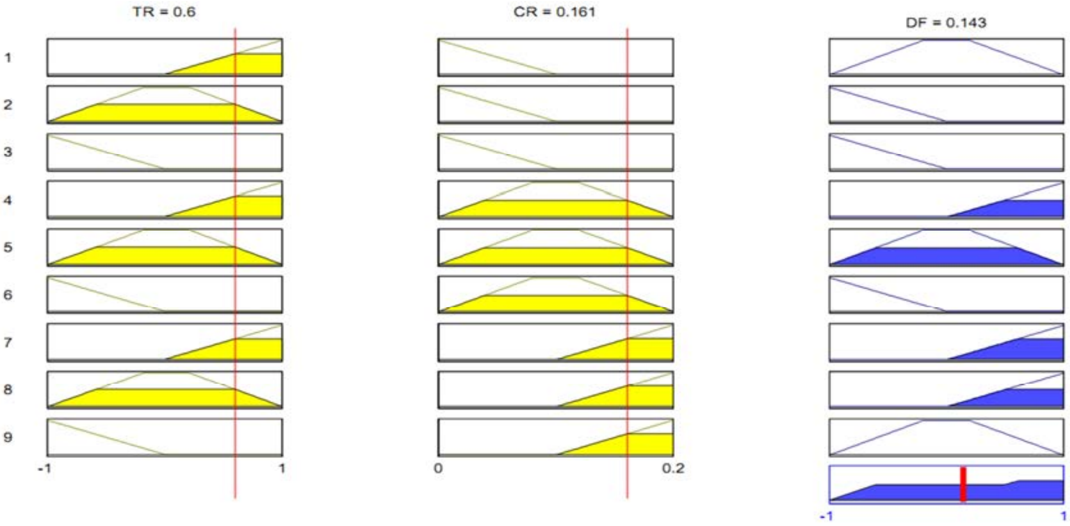

Fig. 5. DF Calculation

DF is calculated for each RN and the RN which gives the highest value will be chosen from the candidate position of RNs based on the budget and coverage constraints.

3.2 RN deployment phase

RNs deployment scheme based on the budget constraint is illustrated as follows:

Input: Candidate positions of RNs, positions of the UNs, TDC, position of the eNB.
Output: RN placement locations, CR of the UNs and average throughput per user.
Initialization: M (no of RN positions to be selected) =0, V_{in} (throughput function) =0 and temp result=null.
Step 1: Select the candidate positions of RNs within the coverage range of eNB and discard other RNs.
Step 2: DF for each selected RN is calculated based on the fuzzy logic which is mentioned in the section 3.1, with CR and TR as the input parameters of the fuzzy inference engine and arrange the DFs in the descending order.
Step 3: Select the RN which is having the highest DF.
Step4: According to (2) calculate the throughput.
Step 5: Let M=M+1, According to the descending order of DF, RNs with highest DF are selected.
Step 6: If budget constraint function (4) is satisfied, then calculate the throughput value (2) and store the RN position to the temp result then go to step 7.Otherwise, go to step 5.
Step 7: The temp result is the final positions where we place RNs. In addition to that the average CR and average throughput per users of UNs are calculated.

Based on the coverage constraint the RN deployment scheme is illustrated as follows

Input: Candidate positions of RNs, positions of the UNs, expected coverage ratio (E_{CR}), position of the eNB.
Output: RN placement locations, CR of the UNs and average throughput per user.
Initialization: M (no of RN positions to be selected)=0 and temp result=null.
Step 1: Select the candidate positions of RNs within the coverage range of eNB and discard other RNs.
Step 2: DF for each selected RN is calculated based on the fuzzy logic which is mentioned in the section 3.1 with CR and TR as the input parameters of the fuzzy inference engine and arrange the DFs in the descending order.
Step 3: Select the RN which is having the highest DF.
Step 4: Let R be the CR of CUNs for this case and compare R with E_{CR}. If R is greater than E_{CR} then, selected RN position is stored in temp result and go to step 7.Otherwise go to step 5.

Step 5: Let M=M+1, According to the descending order of DF, RNs with highest DF are selected.
Step 6: Check whether E_{CR} is achieved. If it satisfied, then store the position in temp result and go to step 7.Otherwise go to step 5.
Step 7: The temp result is the final position where we place the RNs.

4. Simulation and Result

The performance of our proposed scheme is analyzed using a simulation model. By using Matlab simulator, we showed that our proposed scheme gives the highest performance than the existing schemes**.** The simulation is repeated for different number of candidate positions for the RNs and locations of UNs. Jau-Yang Chang et al. (2014**)** has been proved that the uniform clustering scheme offers better coverage and throughput performance over JBRP scheme. Thus here for comparison JBRP scheme is not considered. The assumptions of our simulation model is described as follows:

- The geographic area is a square with size of 5km×5km
- The system contains eNB, RN and UN.
- It is assumed that the position of eNB is deployed perfectly.
- The candidate position of RNs is distributed randomly in the geographic area and the number of candidate positions for the RNs are 5, 8,11,14,17.
- UNs positions are randomly distributed and the number of UNs is 100.
- The coverage radius of RNs is 0.5 km and coverage radius of eNB is 1.5 km
- The placement cost of a RN and eNB are 3 and 9 units, respectively.
- The data rate between UN and eNB or between UN and RN is calculated based on the Table 1.
- The traffic demand for each UN is taken as 5 Mbps.

Fig. 6. Shows a sample simulation scenario of uniform clustering scheme for a budget constraint of 25 units. In this scenario, 12 candidate locations for the RNs are taken. Since RNs cannot work independently, the RNs outside the coverage area of eNB are neglected for deployment. Thus 8 RNs are alone considered for RNs deployment. Based on the given budget constraint, 5 RNs are selected out of 8 RNs within the scenario area. The selected RNs are RN1, RN2, RN3, RN4, and RN5. For the selected deployment sites average throughput and CR are calculated.

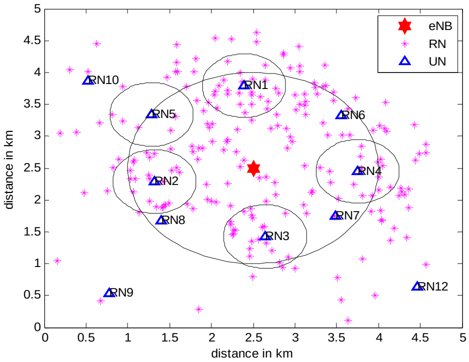

Fig. 6. A sample simulation scenario for uniform clustering scheme with a budget constraint of 25 units.

Fig. 7. Shows a sample simulation scenario of the fuzzy scheme with the same budget constraint of 25 units. We took same candidate location of RNs and user distribution as in Fig.6.The fuzzy scheme selects 5 RNs namely RN1, RN2, RN3, RN4 and RN6. Based on the number of uncovered UNs the RNs is deployed. In uniform clustering scheme, balancing the network load between eNBs and RNs is not considered. An unsuitable placement of eNBs and RNs results in a higher placement budget.

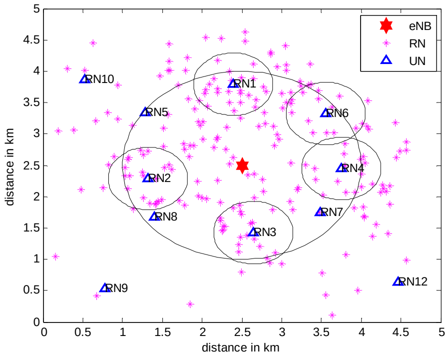

Fig. 7. A sample simulation scenario for fuzzy scheme with a budget constraint of 25 units.

Fig. 8. Shows a sample simulation scenario for the uniform clustering scheme with a coverage constraint of 70%. To achieve the required CR, 6 RNs are selected out of 9 candidate locations. The selected RNs are RN1, RN2, RN3, RN5, RN4, and RN9.

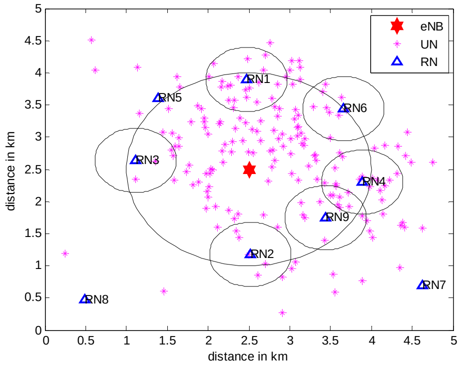

Fig. 8. A sample simulation scenario for uniform clustering scheme with a expected coverage of 70%.

Fig. 9. Shows a sample simulation scenario for fuzzy scheme with the same coverage constraint of 70%.To achieve expected CR, we selected 3 RNs for the deployment. The selected RNs are RN4, RN6 and RN9.

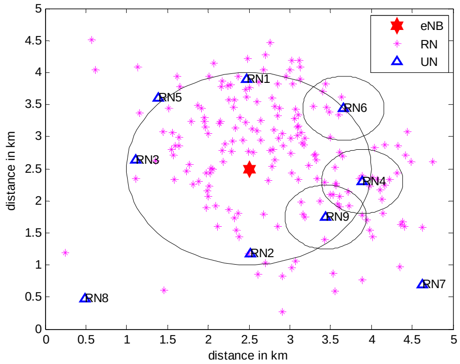

Fig. 9. A sample simulation scenario for fuzzy scheme with a expected coverage of 70%.

Fig. 10. Shows the throughput comparison between fuzzy and uniform clustering schemes for the deployment budget of 25 units. It is observed that the increase in the number of RNs will increase the throughput per user initially. But it is noticed that after certain number of RNs, the average system throughput remains constant due to the co-channel interference between RNs. For all possible combination of RNs the average system throughput per user for uniform clustering and fuzzy scheme are 10.5612 Mbps and 11.675 Mbps respectively. The proposed fuzzy scheme shows an improvement of 7.7% over Uniform clustering scheme.

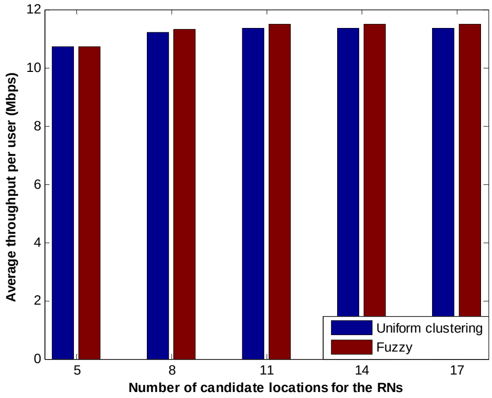

Fig. 10. Average throughput per user (Mbps) vs. Number of candidate locations for the RNs

Fig. 11. Shows the average coverage ratio for the deployment budget of 25 units. The increase in the number of candidate position of RNs will increase the CR. But there is no significant improvement in terms of CR when the number of candidate locations are above 11. For all possible combination of RNs the average CR of the uniform clustering and fuzzy schemes are 73.34% and 78.96% respectively. The proposed scheme shows an improvement of 7.11 % over uniform clustering scheme. Thus our proposed scheme gives optimum RN deployment with increased throughput, reduced cost and high coverage.

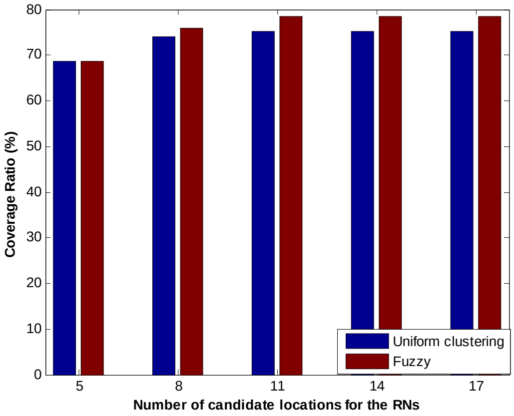

Fig. 11. Average coverage ratio (%) vs. Number of candidate locations for the RNs

Fig. 12. Shows the average throughput per user for an expected CR of 70% .Because of the unsuitable placement of RNs in uniform clustering scheme the average throughput is lower than our proposed fuzzy scheme. For all possible combination of RNs the average system throughput per user for uniform clustering and fuzzy

scheme are 10.2162 Mbps and 11.34625 Mbps respectively. The proposed fuzzy scheme shows an improvement of 9.959 % over Uniform clustering scheme in all the scenario.

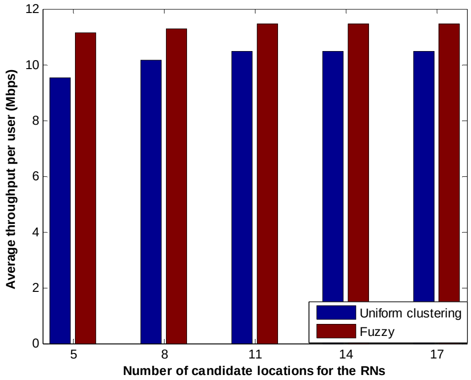

Fig. 12. Average throughput per user (Mbps) vs. Number of candidate locations for the RNs

Fig. 13. Shows the average CR for an expected CR of 70%. For all possible combination of RNs the CR for uniform clustering and fuzzy scheme are 76.1891 Mbps and 84.333 Mbps respectively. The proposed fuzzy scheme shows an improvement of 9.65 % over Uniform clustering scheme in all the scenario.

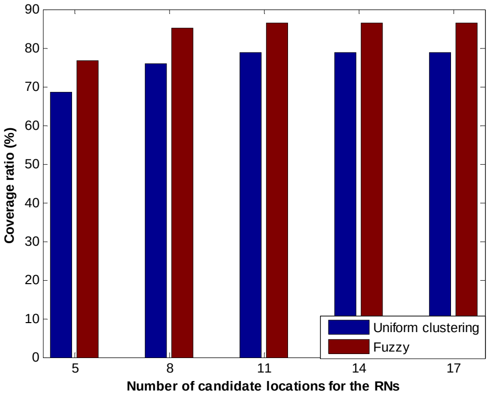

Fig. 13. Average coverage ratio (%) vs. Number of candidate locations for the RNs

The proposed scheme provide better performance for budget and coverage constraint. The main reason is that the fuzzy scheme makes an adaptive decision for deploying RNs from the candidate positions of the RNs. The UNs can obtain an advantageous data transmission rate in MHR network by using our fuzzy scheme.

5. Conclusion

RN deployment in MHR network is an important issue. In this paper a novel fuzzy based deployment scheme for RN is proposed by considering system throughput, coverage and total placement cost. A balanced network load is maintained by fuzzy logic which results a favorable system throughput and coverage. Simulation results showed that our proposed scheme gives high performance in terms of throughput, coverage and cost. As a future work, the performance of proposed fuzzy based RN deployment scheme should be tested under link overloading and inter RN interference conditions.

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