Alternative Enhancement of Associativity Based Routing (AEABR) for Mobile Networks

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Abstract. This study proposes an alternative enhancement for the Enhanced Associativity Based Routing (EABR) method which is a derivation of ABR (Associativity Based Routing) by relative speed and relative distance estimation using the received power strength (RPS) of the nodes. In this study, it is shown that EABR outperforms some other well known protocols. The performance of EABR is improved in terms of number of route reconstructions (RRC) and connected status percentage (CSP). Message overhead and bandwidth utilization is also investigated.

Keywords: EABR, wireless, mobile, ad-hoc, routing.

1 Introduction

In an ad-hoc mobile network there are many randomly located nodes which are moving randomly from one point to another each with a random speed. Therefore, the construction of an efficient route that keeps nodes in communication for the longest time may be quite difficult. Providing maximum life for the routes causes a reduction in number of RRC (Route reconstructions). The enhancements require modifications on the tables and this will create a messaging overhead and RRC trade off. In this study, the performances of some relay selection algorithms (RSA) such as minimum distance path, minmax path, closest node to the source, path according to power threshold and path according to power threshold, EABR (Enhanced Associativity Based Routing) and the new proposed AEABR algorithm are compared in terms of number of RRC by a simulation program under the random speed, direction and initial location parameters. Messaging overhead and bandwidth utilization of these algorithms are also investigated.

2 Method

The system model has six nodes; one transmitter T_x, one receiver R_x, and four relay nodes. The area that the nodes move in is bounded with the specified boundaries and

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the "random waypoint model" [1] is used for the mobility of the nodes in this area. Using this model, each node in the network determines a random destination point before going to that point with a random speed. After arriving at its destination, it pauses there for a random duration and determines a new destination point to go with a random velocity. In this manner, all RSA's and long life path selection algorithms that have been worked on, make their individual selections and keep their own necessary statistics. Since all the algorithms make their decisions in the same conditions with other algorithms, it can be said that the graphs of comparison will be fair.

After simulating all the RSA's as described in section 3, their performance are evaluated in terms of number of RRC and in terms of number of making the same selection with the selection made according to path loss amount among the triangle of R_x,T_x and one of the intermediate relays.

In this study, the proposed AEABR algorithm is compared with the EABR algorithm after making a comparison of RSA's with EABR. This way, AEABR is compared indirectly with all RSA's.

3 Relay Selection Algorithms

When the node T_x tries to sent packets to R_x , a relay through which the packets can traverse will be selected. T_x always additionally uses the direct path from T_x to R_x provided that such a path is available, this way, the signals forwarded by different nodes using AAF (Amplify and Forward) or DAF (Decode and Forward) can be combined at the R_x [2]. During the implementation of the algorithms below, the distance information from each node to R_x and T_x will be needed. If GPS technology were available, the required distances could easily be taken from there as in [3] , but since it is assumed in this study that GPS is not available, the estimations of these distances are done by using the received power formula derived from Free space path loss (FSPL) given in eq. (1) [4]

$$\mathrm{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi f d}{c}\right)^2 = \frac{P_t}{P_r} \tag{1}$$

where λ = signal wavelength (in meters), P_t = Transmitted power (in watts), $\mathrm{P_r}$ = Received power (in watts), c=speed of light (3x 10^8 meters / second), d=distance from T_x to Relay or R_x (in meters), f = frequency of the signal (in hertz),

By retrieving "d" from eq. (1), distance can be found as in eq (2)

$$d(T_x, R_n) = \left(c / 4\pi f \sqrt{\left(\frac{\mathrm{P_r}(R_n)}{P_t} \right)} \right) \tag{2}$$

$d(T_x, R_n)$: Distance from T_x to R_n (meters), R_n: n[th] relay numbered from 1 to 4, $P_r(R_n)$: Power level (in watts) received by R_n

Note that P_t has almost same value for all nodes in a small predefined range.

3.1 Minimum Distance Path

This algorithm uses eq. (2) and selects the relay through which our packets travel through the minimum distance [5]. For each possible route S from T_x to R_x

$$Path_{\min} = \min\left[(d(T_x, R_s^1) + d(R_s^{hc_s-1}, R_x) + \sum_{n=1}^{hc_s-2} d(R_s^n, R_s^{n+1})) \right] \quad (3)$$

where R_s^n : n[th] node on the s[th] route, hc_s : Hop count of the s[th] route.

3.2 Minmax Distance Path

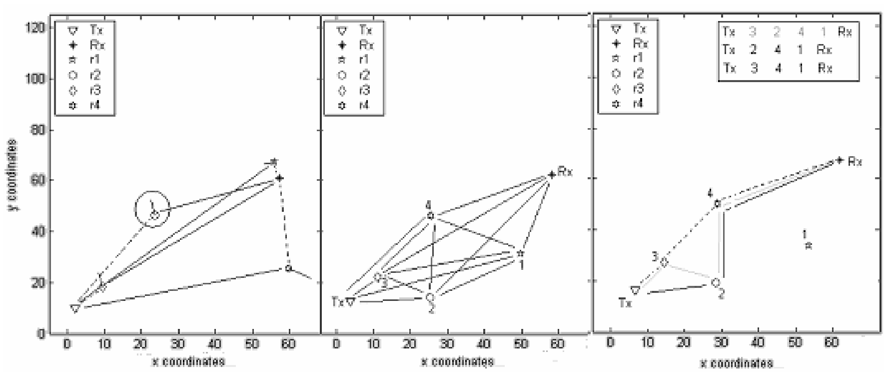
This algorithm selects the path from the set of paths for which the maximum distance between any two linked nodes of the path is lower than all other path's corresponding values, this way enough signal power level received by any node is tried to be provided [5] (See figure 1-a). The maximum partial link distance of each route numbered from 1 to S is found by eq. (4) and among these S routes, the route which returns with the lowest result from eq. (4) is selected by this algorithm.

$$\begin{aligned} Path_s &= \max\left[(d(T_x, R_s^1), d(R_s^1, R_s^2), \ldots\ldots, d(R_s^{hc_s-1}, R_x)) \right] \\ Path_{\min\max} &= \min\left[Path_1, Path_2, Path_3, \ldots\ldots, Path_s \right] \end{aligned} \quad (4)$$

3.3 Relay Selection Using Power Threshold (PT)

In wireless mobile adhoc networks, there are algorithms such as LLRP (Longest Life Routing Protocol) that use discovery packets in order to discover to which node it has access [6] and EABR (Enhanced ABR) in which the destination sends "here I am packets" to its neighbors [7]. In this algorithm, all nodes signature a discovery packet and send it to its neighbors who will also forward these discovery packets to its own neighbors. By this way the relay from which T_x can receive R_x's discovery packet, can forward Tx's packets to R_x, and one of the relays is selected according to eq. (5) for which the Tx receives the signal from R_x with the power level greater than $Power_{Thrs}$ and other relays power levels.

$$(P_r(R_n)) = P_t \cdot \left(\frac{c}{d(T_x, R_n)(4\pi f)} \right)^2 \geq Power_{Thrs} \quad (5)$$



a) b) c)

Fig. 1. a) Minmax distance path chooses the path for which the packets will travel from source to destination via the path whose longest link is the minimum in corresponding distance values of all other possible paths, b) All possible path combinations from Tx to Rx, c) Example of selected paths as a result of EABR algorithm from Fig. 1-b).

3.4 Relay Selection According to Path Loss

If the path loss values between all node connection combinations were always known by the nodes, the nodes would directly use those paths and the path with highest average power level would be selected but it would not lead to long life routes. In order to be able to compare the results of other algorithms with the one made according to path loss, the pathloss values are calculated by eq. (6) for the connections among $R_{x,}$ T_x and each relay. The relay selection is made according to this reley selection algorithm. One of the performance evaluations is the following: since the path loss algorithm selects the strongest and most reliable path, the algorithm, with selections that match the selection of path loss algorithm the most will be the best for this performance criterion, even if it has no effect on having long life route. Evaluating eq. (6) from eq.1 (1) [4]; where units are as in eq. (1)

$$\mathrm{FSPL}\,(\mathrm{dB}) = 20.\log_{10}\left(\left(\frac{4\pi\, fd}{c}\right)\right)20.\log_{10} d + 20.\log_{10} f + 20.\log_{10}\left(\frac{4\pi}{c}\right)$$

$$\mathrm{FSPL}\,(\mathrm{dB}) = 20.\log_{10} d + 20.\log_{10} f - 147.56 \qquad (6)$$

The most important performance evaluation criterion for this study is the life time of the selected relays or paths which is inversely proportional to of number of RRC. Figure 3-d shows the number of RRC graphs of each relay selection algorithm.

4 Long Life Path Selection Algorithms

4.1 EABR (Enhanced Accociativity Based Routing)

EABR algorithm is based on associativity of the nodes as in ABR and uses the ABR algorithm [8], but in EABR, the destination has an active role in RRC, where it was passive in ABR. [9].

4.2 AEABR (Alternative Enhanced Accociativity Based Routing)

The main working principle of the proposed AEABR is a combination of ABR and EABR, and is also an implementation of ABR. The movement of the destination is also taken into the consideration as in EABR. The proposed algorithm differs from ABR in that there exist more than one path having the same number of hops in the set of possible routes determined by ABR algorithm.

In AEABR, all moving intermediate nodes in the network broadcasts “here I am” messages to all available nodes, during this period they also receive “here I am” messages which is also called associativity tick (AT), from all other nodes. These AT messages can only be received if the received power is greater than a predefined threshold power value. By seperately counting the number of AT messages received from each node and calculating an “AT threshold” value each node creates. Each node keeps its own table (see Table 1) which will be used to be informed about the state of all other nodes. The tables are updated by broadcasting discovery messages to all nodes as in LLRP (Longest life routing Protocol) [6], this way, all the nodes are aware of all other nodes tables and all available paths from Tx to Rx in the network. If one of the nodes stops sending AT messages, the corresponding field that keeps the accociativity tick of that node is reset to zero in the table, thus if the AT field is not zero, it is understood from the table that corresponding node is in the range, but having AT value greater than AT Threshold value will also be important. Since all the nodes in the network keeps the tables in the same structure, the nodes can have the indivudial neighbour availability informations of its neighbors from their tables. Once a connection is tried to be established, one of the available neighbour node is selected from the table, and during this selection an other row of the table which includes AT theshold value calculated by AT / (number of nodes) is used, this AT theshold value is continiously calculated for each node according to current state of the network and the connection through this node will be provided if AT > AT Threshold for this node.

On the other hand, the tables will also be used to discover if the node that Tx will connect to, has a path to Rx or not. The tables for a moment that Tx has no direct access to Rx, are given in Table 1.

Table 1. ABR table s of Relay 1, Relay 2, Relay 3, Relay 4, Rx and Tx

table of *R1*	R1	R2	R3	R4	Rx	Tx
Availablity	-	1	1	1	0	0
number of AT	-	3	2	4	7	0
AT Threshold	-	16\6	12\6	14\6	15\6	5\6

table of *R2*	R1	R2	R3	R4	Rx	Tx
Availablity	1	-	1	1	1	1
number of AT	3	-	3	5	4	1
ATThreshold	16\6	-	12\6	14\6	15\6	5\6

table of *R3*	R1	R2	R3	R4	Rx	Tx
Availablity	1	1	-	1	1	1
number of AT	2	3	-	2	4	1
ATThreshold	16\6	16\6	-	14\6	15\6	5\6

table of *R4*	R1	R2	R3	R4	Rx	Tx
Availablity	1	1	1	-	0	1
number of AT	4	5	2	-	0	3
ATThreshold	16\6	16\6	12\6	-	15\6	5\6

table of *Rx*	R1	R2	R3	R4	Rx	Tx
Availablity	0	1	1	0	-	0
number of AT	7	4	4	0	-	0
ATThreshold	16\6	16\6	12\6	14\6	-	5\6

table of *Tx*	R1	R2	R3	R4	Rx	Tx
Availablity	0	1	1	1	0	-
number of AT	1	1	3	0	0	-
ATThreshold	16\6	16\6	12\6	14\6	15\6	-

Table 2. AEABR table of Relay 4

table of *R4*	R1	R2	R3	R4	Rx	Tx
Availablity	1	1	1	-	0	1
number of AT	4	5	2	-	0	3
ATThreshold	16\6	16\6	12\6	-	15\6	5\6

+

Old Power (OP)	**1,3**	**1,8**	**1,19**		**0**	**1**
New Power (NP)	**1,2**	**1,9**	**1,34**	-	**0**	**1**

AT threshold values for nodes are calculated by adding number of AT values in corresponding table and dividing the result to total number of hops in the net, e.g. AT threshold value for R1 is calculated from the table of R1 in Table 1 as in eq (7) ;

$$R_{1_{THRS}} \left(\frac{3+2+4+7+0}{\#\ \text{of nodes}} \right) = 16/6 \tag{7}$$

According to these tables, for a path selection from T_x to R_x, the ABR algorithm in [8] is used. According to this algorithm, the set of possible routes are determined and the one with minimum number of hops will be selected from this group. If there are more than one such route with same number of hopcount, one of them is randomly selected. AEABR comes in to consideration at this point.

We propose a method with AEABR that at first selects the routes with same number of hopcounts from these selected paths. Following this a new tabling mechanism comes into consideration, in this mechanism, two extra rows for which large buffers are not required, are added at the end of each node's own existing table as seen in Table 2. These rows includes the received AT messages power values from all the nodes in the network, the power levels of received AT messages from the nodes are periodically updated on the NP (New Power) field of the table after shifting the NP row to OP (Old Power) row, this way, the nodes will always have information about the received power changes of all nodes.

Another route selection, which will be made among the paths decided by EABR algorithm, will be done by using the OP and NP fields of their tables. Once the set of paths that came up from EABR algorithm, the tables are followed for each of these paths and average power change of all tied neighbour nodes for each path is calculated using eq. (8), for each possible route S from T_x to R_x

$$Path_{PW} = \left((Pw(T_x, R_s^1) + Pw(R_s^{hc_s-1}, R_x) + \sum_{n=1}^{hc_s-2} Pw(R_s^n, R_s^{n+1})) / hc_s \right) \tag{8}$$

The possible path combination that can be constructed from Tx to Rx is shown in Fig. 1-b). Assuming that as a result of EABR, the 3 paths shown in Fig. 1-c) are selected. At this point, while EABR eliminates the path T_x -3 -2 -4 -1 R_x since it has more hop counts than available minimum hop counts in other paths, and randomly selecting one of the paths which has three hops, the new proposed AEABR algorithm uses NP and OP fields and makes another selection. For the state shown in Fig. 1-c), selection will be done by selection the minimum of eq. (8). Since the minimum change in received power means minimum differentiating in relative distances between these nodes, the path whose links has minimum average power differentiation will be selected, hence the positions, directions and velocities of the notes are all taken into consideration in terms of power level differantiation, without using GPS technology.

5 Messaging Overheads of the Long Life Relay Selection Algorithms

Since 48 OFDM symbols exist in 5 ms., in total 200 frames / second will be sent. On the other hand, since there are 720 sub channels, each with 6 bits (64 QAM) [10] (720x 6) / 30 = 144 bits (without FEC) per sub channel will be sent in 5 ms. Using ¾ FEC, this ratio reduces to 108 bits per sub channel. This means a device producing 108 bits in 5 ms requires 1 sub channel.

There is an area that the nodes can make movements in, and there are some number of nodes (6 in the simulation) moving in this area, each of these nodes send the necessary information in its table to the nodes that it has access to. Thus, the number of nodes that a node access to and the messaging overhead can be calculated as the following.

For ABR, 2 integer values (2x4 bytes) and 1 floating point number (1x4 bytes) exist in the table for each of the neighbor node (Table 1) in total 12 bytes (i.e. 12x8=96 bits) information exits to send for 1 neighbor node. For AEABR, 2 integer values (2x4 bytes) and 3 floating point numbers (3x4 bytes) exists in the table for each of the neighbor node (tables 2-3) in total 20 bytes (i.e. 20x8=160 bits) information exits to send for 1 neighbor node. Since each node will send its complete table to its neighbors, the data size that will be sent is dependent on the number of neighbor nodes;

For ABR: Number of neighbors x (3x4 bytes) = Number of neighbors x 96 bits

For AEABR: Number of neighbors x (5x4 bytes) = Number of neighbors x160 bits

As seen from the calculation above if ABR has only 1 neighbor, it needs only one subcarrier and uses only 96 bits of 108 bits (without FEC) where 108-96 = 12 bits (% 11) are wasted. On the other hand, if AEABR has only 1 neighbor, it will need an extra subcarrier and uses only 160 bits of 108x2=216 bits (without FEC) where 216-160 = 56 bits are wasted, which means 28 bits (%13) in a subcarrier is wasted, but for a complete analysis for message overheads and wasted bandwidths of ABR and AEABR these values are analyzed for different number of total nodes (from 1-100) in the area and different number of neighbors of a node which can be calculated as;

$$\text{Number of Neighbor} = \frac{(\text{range of the node . total number of nodes in the area})}{\text{AREA}} \tag{9}$$

where range of the node can be calculated using eq. 2 by equalizing the P_r to power threshold value.

The resultant graph for the range of message overheads and wasted bandwidths of ABR and AEABR for different number of total nodes (from 1-1000) in the area (100x120 meters) and different number of neighbors of a node is illustrated in Fig. 2.

For the case we have in our simulation ABR will send 96 bits and AEBR will send 160 bits per neighbor so the wasted bit amounts for different number of neighbors will be as seen in Table 4.

Table 3. Mobile WiMAX (802.16) data rates with PUSC sub channel (Wimax Forum) [10]

System parameter	Downlink	Uplink	Downlink	Uplink
System bandwidth	5 MHz		10 MHz	
FFT size	512		1024	
Data subcarriers	360	272	720	560
Sub-channels	**15**	**17**	**30**	**35**
Symbol period		102.9 µ seconds		
Frame duration		5 msec		

Table 4. Budget of sent bits and wasted bandwidth according to the number of neighbor count for ABR and AEABR

ABR	Sent bits	96	192	288	384	480	AEABR	Sent bits	160	320	480	640	800
	Wasted bits	12	24	36	48	60		Wasted bits	56	4	60	8	64
	Neigbours	1	2	3	4	5		Neigbours	1	2	3	4	5

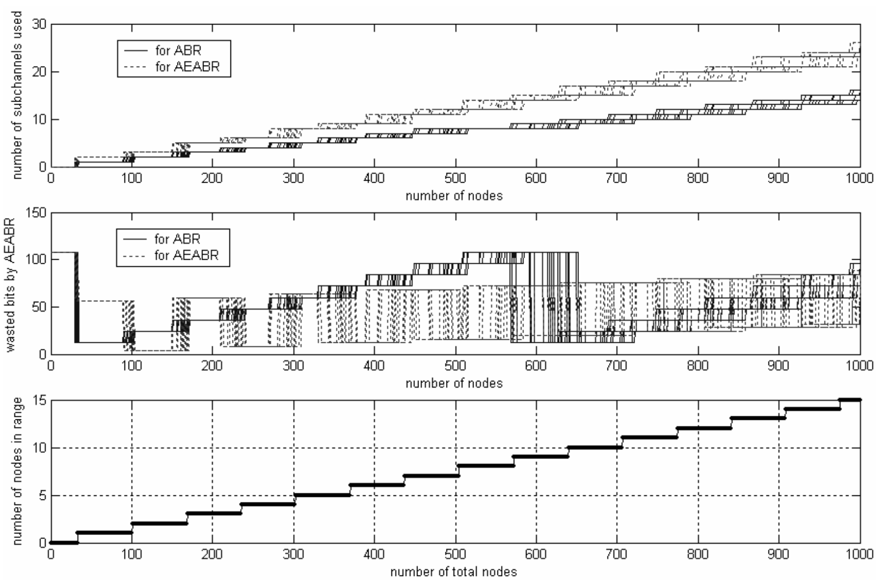


Fig. 2. The range of the message overhead, wasted bandwidth of ABR - AEABR and average neighbor count for according to for different number of total nodes and for different number of neighbors

The wasted bits values can be formulated as in eq. 10 (for ABR) and eq. 11 (for AEABR)

For ABR: $(Neighbor\ count \bmod 2)\, x 12$ (10)

For AEABR:

$$\left\{ \begin{array}{l} \left\{ 4x\left[\text{int}\left(\dfrac{Neighbor\ count}{2} \right) + 1 \right] + 52 \right\} x\,((Neighbor\ count) \bmod 2) \\ + \left(\dfrac{Neighbor\ count}{2} \right) x 4 x (1 - (Neighbor\ count\ \bmod 2)) \end{array} \right\} \bmod\ 108 \quad (11)$$

6 Results and Discussion

6.1 Results of the Relay Selection Algorithms

For RSA's mentioned above, in order to be able to compare the results of other algorithms with the ones made according to path loss values, the path loss values are calculated using eq. (6) for the connections between R_x , T_x via each of the relays. Relay selection is made according to path loss RSA. In one of the performance evaluations, the algorithm with most selections matching the selection of path loss algorithm will be the best for this performance criterion. In Fig. 3-a), the result of the simulation

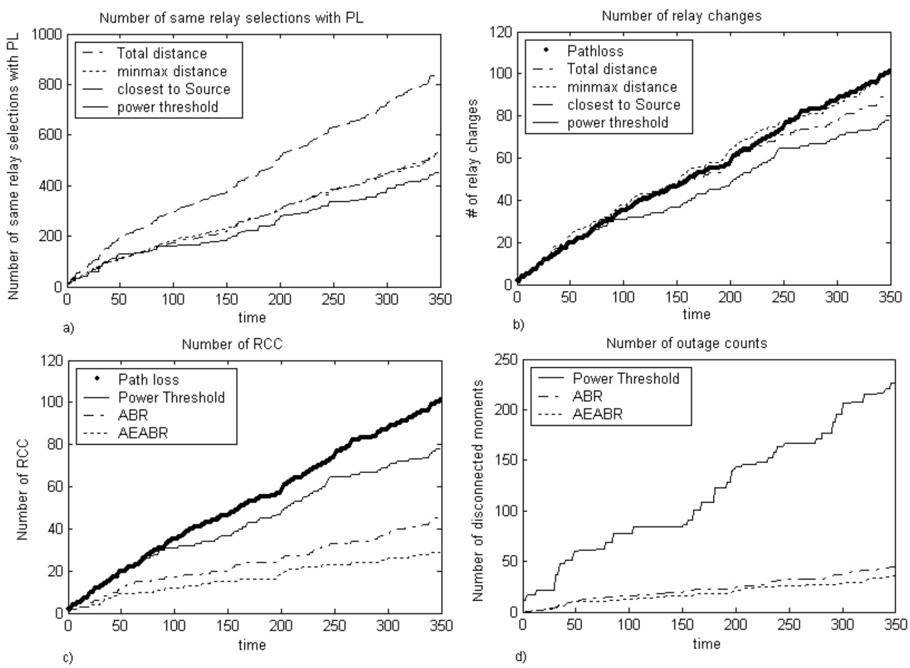


Fig. 3. a) Number of relay selections that matches the selection done according to path loss b) Number of RRC for each RSA c) Number of RRC for path loss, power threshold, EABR and AEABR d) Number of moments that T_x and R_x couldn't get connected (TRCC)

which is also reached in [2], indicate that, since its selections match the path loss algorithm's selections the most, the best selection with minimum path loss are made with the "closest to source" algorithm.

Another performance evaluation criterion for RSA's is the life time of the selected relays or paths which is inversely proportional to number of RRC. Fig. 3-b) shows the number of RRC graphs of each RSA. Since PT has minimum number of RRC's in Fig. 3-b), it is clearly seen that the PT algorithm is one of the best algorithms. From the results from Fig. 3-c) and Fig. 3-d), it can be deduced that, using PT in AEABR is a good choice, that is why the received power level is used in acceptance of received AT's and making the desicion according to average power change of all links in each path in eq. 8 and min of eq. 8.

6.2 Results of the Long Life Path Selection Algorithms EABR and AEABR

As a result, it is seen in Fig. 3-c) that the newly proposed algorithm provides a % 34.78 decrease in number of RCC's from 46 to 30 in 350 seconds from the performance of EABR which also has much better performance than path loss relay selection algorithm. Since the PT relay selection algorithm is one of the best of RSA's according to Fig. 3-b), EABR and AEABR are indirectly compared with all other RSA's in terms of number of RRC's, and it is seen in Fig. 3-c) that AEABR has the lowest number of RCC and it has the highest performance. Note that more than one intermediate node can be used in path constructions when necessary. On the other hand, in the proposed algorithm, while the numbers of RRC's are reduced, the number of moments that T_x and R_x couldn't get connected (number of TRCC) at least must not increase even if it does not decrease. From Fig. 3-d), it is seen that this condition is also satisfied by AEABR, because the line of AEABR mostly lies below the line of EABR line in time vs. TRCC graph.

7 Conclusion

An alternative enhancement for Accociativity Based Routing algorithm is developed and compared with EABR (Enhanced Associativity Based Routing). It is seen that AEABR (Alternatine Enhancement on Accociativity Based Routing) has higher performance than EABR which also has much more better performance than all other well known single hop relay selection algorithms such as minimum distance path, minmax path, closest node to the source path according to power threshold and path according to path loss. It is also seen from the results that the links on the paths constructed by AEABR can stay conneced for more time than all other algorithms including EABR (see Fig.3-d).

On the other hand, it is also seen from figures that, usage amounts of some relay 1 does not differ for EABR and AEABR, while it significantly differs for relays 2, these conditions are directly dependent on both speeds of the nodes and if the moving relays are in opposite directions or in the same direction with T_x or R_x. During all these improvements there is a tradeoff between the message overheads and reducing the number of route reconstructions. As seen from figures that, the number of sub carriers used by AEABR increases by increasing neighbor count, but even AEABR uses 2 sub channels where ABR uses only one for a single neighbor, this rate reduces to two third for greater number of neighbors, another important point that worth to investigate is the amount of the wasted bits in the sub channels during the transmission. Tables show the sent and wasted bits in a 802.16 network for which the values can be calculated using derivations. Another important point for the amount of wasted bits in the sub channels is, AEABR wastes less bandwidth if the number of neighbors of the node is between 5 -9 or greater than 15, which corresponds to 300-600 nodes and 1000 nodes in the area respectively. Also, it is also noticeable that AEABR has a wider range of wasting bandwidth and has always lower minimum values than ABR where maximum values are almost always greater.

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