Location Based Transmission Using a Neighbour Aware-Cross Layer MAC for Ad Hoc Networks

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Abstract. In a typical Ad Hoc network, mobile nodes have scarce shared bandwidth and limited battery life resources, so optimizing the resource and enhancing the overall network performance is the ultimate aim in such network. This paper proposes anew cross layer MAC algorithm called Location Based Transmission using a Neighbour Aware – Cross Layer MAC (LBT-NA Cross Layer MAC) that aims to reduce the transmission power when communicating with the intended receiver by exchanging location information between nodes in one hand and on the other hand the MAC uses a new random backoff values, which is based on the number of active neighbour nodes, unlike the standard IEEE 802.11 series where a random backoff value is chosen from a fixed range of 0–31. The validation test demonstrates that the proposed algorithm increases battery life, increases spatial reuse and enhances the network performance.

Keywords: Power controlled transmission · MAC · Ad hoc networks

1 Introduction

In a resource-constrained Ad Hoc network, interference is a significant limiting factor in achieving high throughput. As the interference range is directly proportional to the transmission range, controlling transmission range of the active nodes dictates the density of parallel or simultaneous communication, subsequently, the overall network performance. Using a large transmission range does have its benefits, as it reduces the path length and increases link stability and throughput, but the resulting interference increases heavily and the network performance degrades as the number of the active nodes increases. On the other hand, when the transmission range is low, the overall interference decreases, but path length between the source and the destination increases; as a result the end-to-end throughput may decrease since throughput decays as the communicating path length increases as discussed by authors of [1], but the reuse factor in terms of frequency and space increases, thereby increasing the probability of parallel transmission. In this paper mobility is not taken into account, so route maintenance is not considered, but focuses on the power controlled Medium Access Control (MAC) using a single hop communication and tested extensively with both fixed and random topologies with random sources and destinations.

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Authors of [2–4] provides a thorough study on different power control MAC for wireless Ad Hoc networks, but most of the approaches uses a fixed maximum power transmission for control frames like RTS and CTS, and uses a low transmission range for Data and ACK frames, the flaw in such approach is that the probability of concurrent transmission is less, since a higher degree of neighbouring nodes will be disturbed by the RTS and the CTS control frames. Some other technique uses a set of power levels as described in [5], where the power level is increased step by step until the next hop neighbour is discovered or maximum power is reached, whichever is earlier; the flaw of such approach is that each node will try with different transmission power levels without knowing whether it will result in successful discovery of next hop neighbour or not.

When a pair of communicating nodes is close to each other, using a fixed transmission power leads to a significant interference and waste energy unnecessarily, as shown in Fig. 1(I). On the other hand, if a node communicates with the next hop destination uses only the required minimum transmission power as shown in Fig. 1(II), then the area of interference decreases, probability of parallel transmissions increases and prolongs battery life, which is the notion of this paper. This paper also focuses on drawing a relationship between the amount of energy spent by an active node and the distance between the communicating nodes. In order to decrease waiting time during low congestion, a new MAC with a dynamic backoff ranges based on the number of active neighbours is also considered in this paper rather than using a fixed backoff ranges.

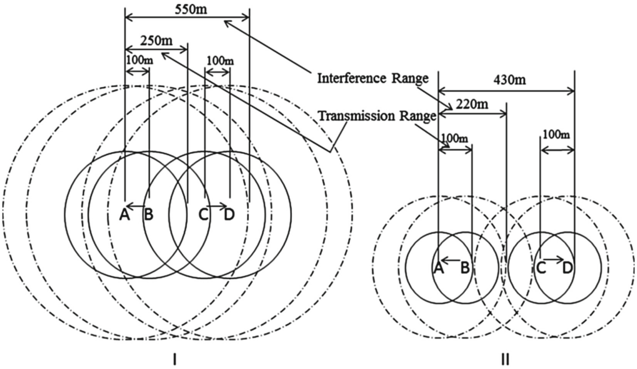

Fig. 1. Using a fixed transmission range (I) and using a location based power controlled transmission (II).

2 Transmission Power Control in Ad Hoc Networks

Different approaches were investigated by various authors to reduce interference and improve the performance of the overall network by controlling the transmission power. A power controlled MAC called POWMAC is discussed in [7], which is an extension of their previous work done in [6]; the author uses the RTS and the CTS control frames for exchanging the signal strength and it exchanges N number of RTS/CTS pairs for securing N concurrent transmissions, so this approach involves a significant control overhead. In order to reduce the signaling burden, authors of [8] proposed an adaptive power control MAC by using only the RTS and CTS for collecting transmission power of the active neighbours and interference level; in order to validate its claims, the study assumes that the transmission range and the carrier sensing range are identical, but in reality, the carrier sensing range is much greater than the transmission range. To reduce the degree of collision in such approaches, a new power controlled MAC is proposed in [9] which utilizes the fragmentation mechanism of IEEE 802.11 and controls the transmission power based on the fragmentation technique. The limitation of such approach is that fragmentation does not occur always unless the packet size reaches the Maximum Transfer Unit (MTU) of the link. All these papers consider sending RTS/CTS and/or ACK frames with maximum power and Data with minimum power.

A cross layer technique combining scheduling, routing and power control transmission is proposed in [10], based on the Time Division Multiple Access (TDMA) mechanism; but synchronization could be an issue with such approach in a distributed Ad Hoc networks. Authors of [11] shows that in optimal power control mechanism approaches to improve spatial reuse, senders should not send with just enough power to reach the next hop node, but it should use higher transmission power. A power control transmission based on the interference and distance estimation is designed in [12], but such approach suffers from distinguishing the differences between the low power transmissions for short distance from high power transmission with long distance. Authors of [13] designed a collision avoidance MAC by adjusting the appropriate power level of the source node, so that the active neighbour can withstand its interference level. Another power control MAC where the RTS/CTS are sent with maximum power and the Data/ACK are sent with minimum power is proposed in [14], but the Data packet is send with maximum power periodically, such approach may save power, but the potential probability of areal space reuse is low. To avoid such problems, the authors of [15] introduce a new method where the RTS messages are not sent with a constant maximum power; instead, transmission starts with a lower transmission power, which is also advertised in the message, but the CTS are sent with maximum power to alert any neighbours that have Data to send. Such mechanism tends to lead to varying transmission ranges from a same node, so active neighbours experiences an uneven degree of interference which may lead to unfair end-to-end throughput. Authors of [16] introduce a mechanism where the transmission power is reduced based on the degree of contention by monitoring the contention window. A trade-off between the bandwidth, latency and network connectivity during transmission power control Ad Hoc networks is proposed in [17]. As such, transmission power control can lead to battery durability and space reuse for parallel transmission, but authors of [18] suggest that obtaining an optimal transmission power is an NP-hard problem even if the node has the entire knowledge of the network. So, this paper uses a deterministic approach to optimize the durability of the battery life and enhances the network performance by considering a minimum power needed by each node during data transmission with the help of location information and by observing its neighbour activity. In a multiple channel approach, authors of [19] divides the channels and assigned one for control frames and Data packet, and the other channels for transmitting busy tone and receiver busy tone, but such approach of considering multiple channel consumes too much resources. In order to increase throughput, a joint power and rate control scheme is discussed in [20], which also maximizes the energy efficient, but such approach considers a cognitive radio which allows secondary users to access licensed spectrum band. The authors of [21] designed a power control MAC by considering an optimal hop distance in a dense single cell network, but the approached considers an existence of no hidden nodes. In order to improve the average signal-to-interference ratio, outage probability, and spatial reuse, the authors of [22] studied if discrete power control is better than no power control when the nodes of the Ad Hoc networks are in the form of a Poison-distribution.

The remainder of the paper is structured as follows. The proposed MAC is described in detail in Sect. 3. Section 4 provides the evaluation of the results, and then Sect. 5 concludes the paper by proposing a number of future directions.

3 Power Control Cross Layer MAC

As highlighted by prior research, the transmission power does have a significant influence on the network capacity, particularly for relatively high node density, due to interference. To reduce the impact of these issues, this paper proposes a new cross layer MAC called Location Based Transmission using a Neighbour Aware – Cross Layer MAC for Ad Hoc Networks (LBT-NA Cross Layer MAC). The proposed protocol consists of two parts: calculation and transmitting any Data and control frames using an exact minimal needed power using location information and secondly calculation of a new backoff value which depends on the number of active neighbour nodes. The detail work of the proposed cross layer MAC is described in the following subsections:

3.1 Proposed Power Calculation Model

The proposed model assumes that each node knows its location information, with the help of a Global Positioning System (GPS) and they are exchanged to calculate the distance (d) and the required minimum transmission power between the communicating nodes. This leads to a twofold advantage from an efficiency perspective. Firstly, it uses only the minimal required power between the communicating nodes, so it extends battery lifetime. Secondly, the interfering range changes dynamically depending on the distance of communication, so the probability of simultaneous transmissions without interference increases.

The proposed protocol embeds the location information in Request-To-Send (RTS) and Clear-To-Send (CTS) control frames to avoid additional control overheads. This paper considers only 2D topologies. When a node has a data to send, it starts by broadcasting RTS frame at full power and the intended next hop receiver replies with a CTS control frame to reserve the channel. When the intended Destination node N_D with coordinates $(X_D,Y_D,0)$ receives an RTS frame from a Source node N_S with a coordinate $(X_S,Y_S,0)$, it extracts the location information and calculates the corresponding Euclidian distance $d = \sqrt{(X_D - X_S)^2 + (Y_D - Y_S)^2}$ of two nodes. Likewise, upon receiving a

CTS frame, the sender also calculates the distance between the two nodes. So, the source and the next hop destination are aware of their distances upon receiving the first RTS and the first CTS frames.

In this paper, the maximum transmission power used is (P_t) = 0.28183815 W, a power that can cover a maximum fixed transmission range of 250 m. The interference range covers a radial distance of 2.2 times of the transmission range (default value in NS2). The threshold value of the signal strength to be considered within a transmission range is 3.652e-10 W and a signal received up to 1.559e-11 W is considered to be within an interference range.

$$Cross\_Over_{distance} = 4\pi h_t h_r / \lambda \tag{1}$$

$$P_t = P_r (4\pi d)^2 L / G_t G_r \lambda^2 \tag{2}$$

$$P_t = P_r d^4 L / G_t G_r h_t^2 h_r^2 \tag{3}$$

In this paper a Dumb Agent routing technique is used as it discovers a one hop path length. Initial route discovery packets are always sent with maximum transmission power since the node has no information about the location until RTS/CTS packets are exchanged. If the location information received through the exchanged control frames is unchanged for the communicating pair, then the distance need not be re-calculated. Based on the distance information and the minimum receiving signal strength i.e. *RXthresh_*, new transmission power is calculated using (2) for the Friss propagation model and uses (3) for Two Ray Ground propagation model. The Friss model is more efficient to Two Ray Ground propagation model when a distance of communication is short. Here in this paper both the propagation models are considered and the node activates to one of the propagation models based on the distance between the communicating pair. A crossover distance between the two communicating nodes is calculated using (1). Crossover distance is a critical distance after which the received power decays with an order of d^4, so whenever the distance crosses the crossover distance Two Ray ground propagation model is used, otherwise Friss model is considered. Authors of [23] analyse and concludes that the Two Ray Ground propagation model also has its own limitations in real life application in comparison to basic Freespace model like Friss and the authors introduces a new propagation model based on the phase difference of interfering signals and a reflection coefficient which yields to a better results for an unobstructed communication between the sender and the receiver.

The algorithm for adjusting the transmission power for a routing packets using Dumb Agent, any MAC control frames RTS/CT/ACK and Data packets is described in Table 1 and a record of the RTS/CTS frames of all the active neighbour nodes is maintained by each node as shown in Table 2. The node records the IDs of the source-destination pair of the active neighbours, the timestamp of the frame, the position information of the active neighbour, and the NAV duration information. During updating the active neighbour table, records with a timestamp older than T second from the current time are removed from the list, and here in this paper T = 1 s is considered, it is done in order to maintain the freshness of the network condition and remove the entry of those nodes which are no longer active.

Table 1. Algorithm for adjusting the transmission power.

```
When node i has to transmit to node j

If [Pkt_type == Routing] then
   If [(ID_i^{Sent_cts} → ID_j) == Yes || (ID_j^{Received_cts} ← ID_i) == Yes ] then
                 Transmission_Power_i = Power_New
   Else
                 Transmission_Power_i = Power_Max

Else If [Pkt_type == PT_MAC && PT_MAC = RTS || PT_MAC = CTS ] then
      If [RTS_CTS^{Sent}_{i to j} ≥ 1] then
                 Transmission_Power_i = Power_New
      Else
                 Transmission_Power_i = Power_Max
Else If [Pkt_type == PT_MAC && PT_MAC = ACK || PT_MAC = DATA] then
                 Transmission_Power_i = Power_New
```

Table 2. Algorithm for collecting active neighbour information

```
When node i overheard packet/frame from node j

If [Power_recv ≥ RXthresh_ && Dst_j ≠ ID_i && Pkt_type == RTS/CTS] then
      If [Record_Count_Neigh_i == 0] then
            Active_i^{Neighbour}[0] ← {ID_j, Dst_j, Time_j, x_j, y_j, z_j, NAV_j}
                  Record_Count_Neigh_i ++;
      Else
         For [i = 0 ; i < Record_Count_Neigh_i ; i ++]
          Do
           If [Active_i^{Neighbour}[i].ID == ID_j && Active_i^{Neighbour}[i].Dst == Dst_j] then
                Active_i^{Neighbour}[i] ← {Time_j, x_j, y_j, z_j, NAV_j}
                Break;
           Else If [ i + 1 == Record_Count_Neigh_i]
                Active_i^{Neighbour}[i + 1] ← {ID_j, Dst_j, Time_j, x_j, y_j, z_j, NAV_j}
                Record_Count_Neigh_i ++;
                Break;
           Else
                Continue;
          Done
```

3.2 Proposed Exponential Backoff Mechanism

The new backoff mechanism is designed based on active neighbour information. Each active node maintains three-level of degree of contention (C_d); where $C_d = 0$, if $Active_i^{Neighbour} = 0$; $C_d = 1$, if $Active_i^{Neighbour} \leq 2$; and $C_d = 2$, if $Active_i^{Neighbour} \geq 3$. The degree of contention (C_d) and the retrial number (r) controls the exponential contention window size as shown in (4). The contention random backoff value doubles whenever the transmission fails. When the number of active nodes within its transmission range is Low, Average and High, the maximum allowable contention window value is 255, 511 and 1023 respectively. If the calculated $CW_{C_d,r}$ goes beyond the given maximum contention window sizes then it takes the provided maximum values.

$$CW_{C_d,r} = \begin{cases} 2^{(3+C_d)} - 1;\ r = 0 \\ 2^{(3+C_d+r)} - 1;\ r \geq 1 \end{cases}$$
$$\text{Where: } \mathrm{C}_d = \{\text{Low } = 0,\ \text{Average } = 1,\ \text{High } = 2\}$$
$$\mathrm{r} = \{0, 1, 2, \ldots\ldots, 7\} \tag{4}$$

4 Evaluation and Discussion

The proposed cross layer transmission power controlled MAC was tested in different scenarios and benchmarked against the IEEE 802.11 and IEEE 802.11e standards. All simulations were carried out with NS2, version 2.35. with the network parameters listed in Table 3 and an antenna parameters such as Transmitter Gain ($G_t = 1.0$ dBd), Receiver Gain ($G_r = 1.0$ dBd), Height of Transmitter ($h_t = 1.5$ m), Height of receiver ($h_r = 1.5$ m), Frequency (f = 914.0e6 Hz), wavelength (λ) of the corresponding frequency, System Loss (L = 1.0) are considered.

Table 3. Network simulation setup.

Parameter	Value/protocol used
Grid Size	2000 m × 2000 m
Routing Protocol	DumbAgent
Queue Type	DropTail
Queue Size	100
Bandwidth	2 Mbps
SIFS	10 μs
DIFS	50 μs
Length of Slot	20 μs
Power_{Max}	0.28183815 W
Default RXThresh_	3.652e-10 W for 250 m
Default CSThresh_	1.559e-11 W for 550 m
CPThresh_	10.0
$\mathrm{Max}_{\mathrm{Retry}}$	7
Simulation Time	1000 s
Traffic Type	cbr
Packet size	1000 bytes

4.1 One Hop with a Single Source-Destination Pair

Since, LBT-NA Cross Layer MAC is a power control communication mechanism, when the communicating nodes are closer, the amount of energy spend is less compared to the situation when the communicating nodes are of greater distance. It is also considered that if a node is in a sleep mode then the amount of power consumed in a second is 0.001 W, when a node goes to an idle state from a sleep state it requires 0.2 W of power and the time required to wake up is 0.005 s. Each node is charged with 1000 Joules of energy and simulation is carried out for 1000 s. The transmission power of a node for LBT-NA Cross Layer MAC is adjusted as per the location of the destination node, but for the standard IEEE 802.11b and IEEE 802.11e, a fixed transmission power of 0.28183815 W is used.

By using the network parameters listed in Table 3 and a cbr traffic with an offered load of 2000 kb/s, Fig. 2 depicts the level of remaining energy of a source node when the communicating nodes are static with an initial distance of 50 m and then the communicating distance is increased by a factor of 10 m after every n rounds of simulations up to a maximum distance of 250 m.When the communicating nodes are separated only by 50 m, then the amount of energy the source saves using LBT-NA Cross Layer MAC is 38 % over IEEE 802.11b, 35 % over IEEE 802.11e with highest priority traffic and 40 % over IEEE 802.11e with lowest priority traffic. Even when the source and the distance is 250 m away from each other, a node using LBT-NA Cross Layer MAC still uses less energy due to the use of new backoff mechanism where a node with less active neighbours backs off with smaller value as described in Sect. 3.2.

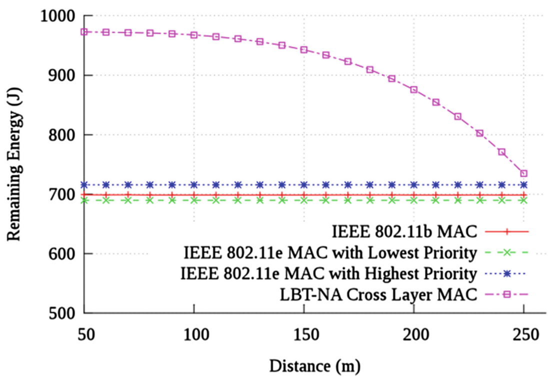

Fig. 2. Remaining energy of data traffic generator vs distance of communication.

Figure 3 shows the remaining level of energy of a destination node when the distance of communication with the source increases. IEEE 802.11b and IEEE 802.11e use a constant energy unlike LBT-NA Cross Layer MAC due to the fixed transmission power method. The new protocol performs better in terms of saving energy even at the destination node. A small range of backoff value (0–7) is used in LBT-NA Cross Layer MAC when there are no active neighbours and in that of IEEE 802.11e with highest priority traffic, so it saves more energy to that of IEEE 802.11b and IEEE 802.11e with lowest priority traffic since sensing and waiting time is reduced. In a long distance communication, IEEE 802.11e with highest priority traffic saves more energy to that of LBT-NA Cross Layer MAC. When the distance of communication is short, the amount of energy saved by a destination node using LBT-NA Cross Layer MAC is 8 % over the standard IEEE 802.11b, 4 % over the node using IEEE 802.11e with traffic flowing with lowest priority.

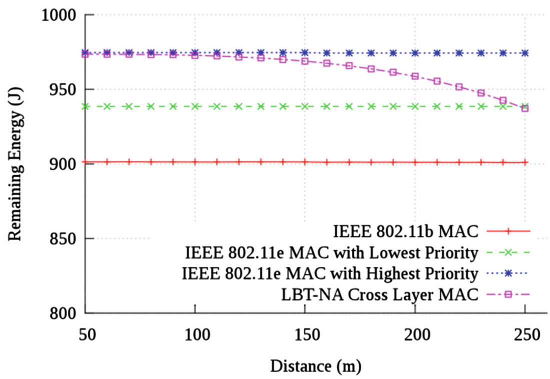

Fig. 3. Remaining energy of a receiver vs distance of communication.

4.2 Multiple Sources with Parallel Communication

Considering the topology shown in Fig. 1, where node B sends to node A and node C sends to node D, both the sources are exposed to each other, when the nodes uses a fixed transmission range of 250 m, so the bandwidth is shared. But when the proposed LBT-NA Cross Layer MAC is used, parallel communication is possible because node B's interference range (220 m for a transmission range of 100 m) does not disturb the sending activity of node C, and vice versa, so the overall network performance enhances.

Figure 4, confirms that using a fixed maximum transmission power methods like IEEE 802.11 cannot exhibit parallel transmission for a topology arrangement shown in Fig. 1 and the network saturates faster when the offered per flow loads are 710 kb/s and 450 kb/s for IEEE 802.11b and IEEE 802.11e respectively, unlike the newly proposed MAC which saturates at a very high data rate1425 kb/s. It shows a performance gain of above100 % over IEEE 802.11b and a gain of above 300 % over IEEE 802.11e MAC. Since the numbers of active nodes around each active source are few, the new backoff mechanism further enhances the overall network performance.

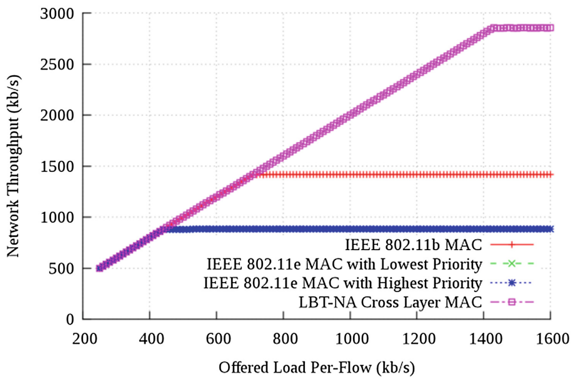

Fig. 4. Network performance with parallel transmission.

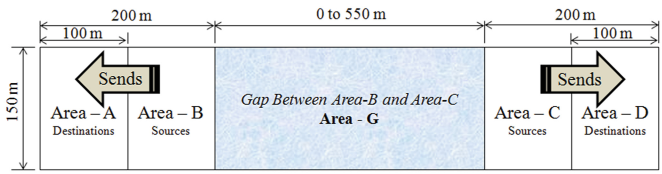

Fig. 5. Random topology with fixed boundaries

4.3 Random Topology

Since, IEEE 802.11e MAC is not competitive in terms of network performance; hereafter the proposed MAC, LBT-NA Cross Layer MAC is compared only with IEEE 802.11b MAC. In order to validate the robustness and test the performance of the proposed technique, a more realistic random topology with a defined space boundary is considered as shown in Fig. 5, using the network parameters listed in Table 3. The topology space is divided into four 150 m × 100 m sections with same areal space called Area-A, Area-B, Area-C and Area-D, with each section containing 10 nodes which are placed randomly. The fifth areal section called Area-G is considered with its areal length varied from (0 m to 550 m) × 150 m to separate Area-B and Area-C. Destination nodes are selected randomly, from Area-A and Area-D for the random sources which are picked from Area-B and Area-C respectively. The space divided as shown in Fig. 5 allows any node deployed in one section can communicate with a node deployed with the next consecutive sectional area with one hop communication, considering that the maximum transmission range is 250 m. The Area-G which separates the areal sections Area-B and Area-C is increased by a factor of 10 m and analysed the overall network performance using a UDP connection with cbr application as well as TCP traffic with same packet sizes of 1000 bytes. The per flow data rate offered in the network is 2000 kb/s in case of cbr traffic.

Figure 6 shows the network performance of a random network topology setup of Fig. 5. As the Area-G widens the network performance of the proposed protocol LBT-NA Cross Layer MAC increases rapidly unlike a fixed transmission range methods where the performance increases only after the length of the Area-G is greater than 270 m. When the length of the Areal-G is 200 m, the performance gain of cbr and tcp traffic of the proposed method against the IEEE 802.11b is 73 % and 63 % respectively. Such increased in performance is due to increase in probability of parallel transmission of the exposed sources. During network saturation and areal reused, use of low contention window for less active neighbours leads to a gain of 30 kb/s in case of cbr traffic in LBT-NA Cross Layer MAC over IEEE 802.11b, but for tcp traffic such method leads to reduction of sliding window and results in lowering the performance.

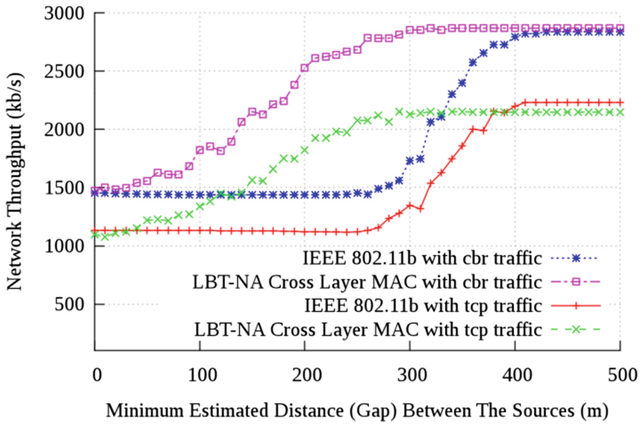

Fig. 6. Network performance of random sources and destinations

5 Conclusion and Future Direction

This paper proposed a new MAC called LBT-NA Cross Layer MAC where transmission power is controlled based on the location and uses a new random backoff values based on the number of the active neighbour around the node. In such mechanism, the performance of the network in terms of spatial and bandwidth reuse are better compared to a fixed transmission range methods. The durability of the battery life increases since, the system uses only the required transmission power during communication, and moreover the backoff values is directly proportional to the number of active neighbours, there is a performance gain of 30 kb/s when cbr traffic is used at a saturation region. The proposed protocol is also tested with random topologies to validate and investigate its efficiency.

Future work will be focussed on estimating power instead of using location information and considers signal strength of active neighbour's transmission to provide fairness and uses a dynamic Extended Inter Frame Spacing (EIFS) instead of using a fixed one as considered in IEEE 802.11 series when packet error or collision or capture occurred; since packets are generally of different sizes.

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