Channel Quality Based Adaptive Gossip Flooding Mechanism for AODV

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***Abstract*—This On-demand route discovery mechanism of reactive protocols based on flooding of route request packets faced serious excursion of "broadcast storm". Moreover, frequent path breakages are experienced due to link failures, as an impact of time varying characteristics of radio channel and/or node mobility. In this paper Channel Quality Adaptive Gossip Flooding mechanism for Ad hoc On-demand Distance Vector (AODV) routing protocol, named CQAG-AODV is proposed as a solution to these issues. CQAG-AODV is a cross layer approach, where in route discovery mechanism of AODV is tuned to signal quality of wireless channel. Flooding of route requests (RREQs) is controlled with probabilistic measures based on signal strength observed at the physical layer. Proposed scheme tries to discover robust paths by forwarding more RREQs along good signal quality links rather than on weaker ones. The proposed scheme is implemented using Qualnet simulator and performance is evaluated in terms of PDR, throughput, end to end delay and link breakage. Simulation results show that CQAG-AODV significantly curtails the link breakages with reduced RREQ forwarding overhead compared to conventional AODV and thus takes care of "broadcast storm" problem.**

Keywords—MANET; AODV; Gossip; RSS; broadcast storm

I. INTRODUCTION

Mobile Ad hoc network, MANET [1], is a network of wireless devices that have routing capabilities, have gained popularity due to ease of deployment and diverse application domains e.g. war fields to vehicular communication. Varieties of routing protocols have been developed for such networks which are broadly classified as Proactive, Reactive and Hybrid routing protocols. Due to their on-demand nature, reactive protocols e.g. AODV [2], etc. outperformed their counterparts and thus are widely adopted.

Nodes using reactive protocols initiate route discovery procedure when they have packets to be delivered to destination for which path is not readily available. Route discovery procedure relies on flooding of special request packets called route request (RREQ) packets. The route is discovered through multiple rebroadcasts (i.e. flooding) of RREQs by intermediate nodes. Flooding results in two serious problems viz; "broadcast storm" problem [3] and resource consumption of the nodes/network. The blind flooding of RREQs without due consideration to node or network status, results in wastage of node battery power as well as network bandwidth, if the discovered path cannot sustain longer. As multi-hop ad hoc networks are characterized by node mobility and time varying characteristics of wireless channel, if the links contributing to discovered paths are already weak, path breakages will be frequent and the efforts taken to discover them will be wasted.

To address these issues Channel Quality Adaptive Gossip flooding mechanism for AODV is proposed. CQAG-AODV attempts to discover robust paths in terms of signal strength by flooding more RREQs along links with higher signal strength. This is a cross-layer design based probabilistic flooding approach, in which the channel quality at physical layer is used to adaptively select the RREQ forwarding probability. The received signal strength (RSS) value of the link along which RREQ arrived is used for deciding its forwarding probability.

Various optimization approaches for solving the problems caused due to interference in ad hoc networks are suggested [4-7]. Routing metrics based on the signal to interference and noise ratio (SINR) of the channel are proposed. It is experimentally proved that network performance is quite improved in different propagation and interference scenarios. However, these approaches seldom address the "broadcast storm" problem. Rather, by loading link status information in the control packets (RREQ or Hello), these schemes may increase routing overhead. Our goal is to improve the overall network performance under diverse propagation conditions with least control overhead. Although the above mentioned approaches utilize the same metric of signal quality at the physical layer as of ours, proposed CQAG-AODV does not take into account interference in the routing decision. This is so because; interference affects the capacity of the network and not the connectivity between nodes. We believe by selecting links that offer better signal strength will implicitly reduce the effect of interference.

Goal of this work is to control the "broadcast storm" problem by reduced flooding of control packets and minimizing the path failures caused due to link failures between nodes. Our contributions in this work are twofold:

- To control the "broadcast storm" problem by probabilistically forwarding reduced number of RREQs, without degrading network performance.
- Discovery of good quality paths, robust to link failures, so that route discoveries triggered on path failures are avoided.

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This is achieved by tuning the RREQ forwarding probability with the signal strength observed at the physical layer.

The rest of paper is organized as follows. Section II presents survey of different optimization approaches suggested in the literature. In section III network model based on channel quality is presented and our CQAG flooding mechanism is proposed in section IV. Section V provides the implementation details. Simulation environment and performance evaluation is presented in sections VI and VII respectively. Section VIII concludes the paper.

II. RELATED WORK

The performance of reactive protocols is degraded mainly due to resource consumption by redundant control traffic generated for route discovery and maintenance, which increases tremendously in large and dynamically changing topologies. To optimize the routing mechanism of AODV various approaches are proposed.

Haas et.al [8] suggested Gossip based approach in which each node forwards a packet with some probability. The forwarding probability is used as a measure to control RREQ broadcasts. Source node sends a route request with probability 1. An intermediate node that receives a route request broadcasts it with a probability *p*, and discards it with probability (1-*p*). Different variations of gossip scheme are suggested. *Gossip (p, k)* refers to gossiping with probability *p* after *k* hops. It is shown that in all in/finite regular and random graphs when *Gossip (p, k)* is used, the probability that the message does not die out and reaches many nodes is $\theta_k^s(p)$ (< 1). Proposed AODV + G protocol uses *Gossip* (*p*=0.65, *k*=1) in which the probability that messages do not die out in any execution is 95% i.e. $\theta_1^s(0.65) = 0.95$. Gossip protocol saves up to 35% control messages than flooding, without degrading the routing performance.

A neighbor coverage based probabilistic rebroadcast protocol (NCPR) is proposed in [9]. Based on neighbor coverage knowledge of a node, NCPR determines out of all neighbors, how many should receive the RREQ packets. Here intermediate nodes probabilistically forward RREQs; the rebroadcast probability being calculated on the basis of uncovered neighbors, connectivity metric and local node density. Due to less redundant rebroadcast, the number of rebroadcasts is significantly reduced and the proposed protocol mitigates the network contention and collision so as to increase the packet delivery ratio and decreases the average end-to-end delay.

Geographic routing approaches use node's location (coordinates) to forward packets toward the destination in a greedy manner [10, 11]. Since request packets are forwarded only in the direction of destination, the amount of redundant rebroadcasts are reduced. Geographical protocols are scalable since they only use localized neighboring information rather than complete network knowledge for next hop selection, but they need external localization service like GPS.

Hybrid Location-based Ad hoc routing protocol HLAR is proposed in [12]. By combining the features of greedy geographic routing with reactive protocols HLAR efficiently utilizes the location information to reduce the routing overhead. If the location information is not accurate, HLAR uses the basic reactive routing mechanism. The node receiving request packet finds nodes which are closer to destination than itself. If a closer node to destination is available, RREQ is forwarded to that neighbor; else RREQ is flooded to all neighbors. For various node densities routing overhead of HLAR is constant as compared with AODV, where it grows exponentially with node density. End-to-end delay is significantly less and PDR increases as a function of node density.

Estimated distance (EstD) based routing protocol EDRP [13], restricts the propagation range of RREQ messages. EstD is a combination of estimated geometrical distance (EGD) and estimated topological distance (ETD). EGD considers variations in received signal strength (RSS) at contact time of two nodes, to estimate future geometrical distance between them when they move apart. ETD is topology based EstD which aids refinement of EGD in case of inaccurate estimation. Propagation of RREQs in the direction of destination with the help of EstD, significantly reduces the routing overhead and improves the routing performance.

Hybrid flooding scheme is suggested in [14] that combines the features of probabilistic, neighbor based and area based flooding approaches. Intermediate node forwards received RREQs probabilistically. The forwarding probability is based on neighborhood node density and the distance to the neighbors. Hence in dense areas the RREQs are flooded with low probability, whereas in less dense areas RREQs are flooded with high probability. Also, a forwarding zone is defined which restricts the forwarding of received packets to the nodes located within it. Nodes outside the zone do not forward the received packets. Hybrid Flooding incurs less routing overhead as well as lesser energy consumption in dense network as compared to simple flooding or static probabilistic flooding.

III. CHANNEL QUALITY BASED NETWORK MODEL

The received signal strength at a given point over a wireless medium is a function of its distance from the transmitter.

$$P_r = P_t \,.\, G_t . G_r / 4\pi\, d^2 \qquad (1)$$

where P_t and P_r are the transmitted and received signal power, G_t and G_r are the transmitter and receiver antenna gains, and d is distance between transmitter and receiver.

Further, the signal experiences variations due to multipath propagation effects, noise and interference. Due to this time varying characteristic of wireless channel, the received signal power always keeps fluctuating which can be represented by widely accepted time varying multipath propagation model presented in [15], given as:

$$y(t) = \sum_{i=1}^{p(t)} A_i\,(t)\, x\big(t - \tau_i\,(t)\big) + z(t) \qquad (2)$$

where $x(t)$ is the transmitted signal, $y(t)$ is the received signal, $z(t)$ is the background noise, $\tau_i\,(t)$ is the time delay, p(t) is the number of paths and $A_i\,(t)$ is the attenuation of each path.

For a given distance between two nodes, the received signal power fluctuates randomly and thus the successful reception of packet is probabilistic. For a packet transmitted from sender x to be successfully received by receiver y the $SINR_{xy} \geq SINR_{Th}$.

$$P_s = Prob\left[\frac{s}{N+I} \geq \beta\right] \quad (3)$$

where s is the signal strength (RSS), N is the background noise, I is the interference and β is the SINR threshold.

Ignoring the interference and assuming the noise to be normally distributed, SINR can be considered as a function of RSS. i.e. two nodes can establish connection if the received signal power is greater than some predefined threshold ($RSS_{xy} \geq RSS_{Th}$).

$$P_{xy}(c) = Prob\ [\ RSSxy \geq \beta'] \quad (4)$$

where $P_{xy}(c)$ is the connectivity probability of x and y and β' is used to represent threshold β, ignoring noise and interference.

Conversely, the link failure probability or the outage probability between two nodes x and y is

$$P_{xy}(o) = [1 - P_{xy}(c\ )] \quad (5)$$

The default signal strength threshold of a network corresponds to transmission range of the communication system, which is the limiting radius of circular area over which communication is feasible. Since packet reception is based on this threshold, in mobility scenarios frequent link failures are experienced if the mobile receiver is located near the limiting communication radius.

As route discovery procedure of conventional AODV is transparent to signal fluctuations over the physical medium, RREQ forwarding decisions are independent of signal power observed at the link between the forwarding node and its precursor. The RREQs received along good or weak links are treated equally. If the path to destination is contributed by hops consisting of weak links the probability of path failure is more and thus inhibits its use for data transfer.

To overcome this issue we modify threshold β' of equation (4) to $(r * \beta')$ and use this threshold in the route discovery procedure (where r is some constant). The increased threshold $(r * \beta')$ is used only in the RREQ broadcast decisions in the route discovery phase, whereas the default threshold β' is used for data transfer and all other purposes. This ensures that the route discovery procedure finds routes contributed only by good quality hops whose SINR does not fall below acceptable value even if interference or noise levels rise slightly above the average. This reduces link failure probability to some extent when signal fluctuations are experienced due to multipath effects or node mobility.

Use of two different thresholds β' and $(r * \beta')$ is suggested to address the link connectivity issue during data transfer phase. Even though the probability of link establishment is reduced because of higher threshold value used in route discovery procedure, the outage probability during data transfer phase is reduced since its calculation is based on default threshold β' and not on $(r * \beta')$.

IV. CQAG-AODV ALGORITHM

Based on the network model discussed in section III, we propose Channel Quality Adaptive Gossip Flooding mechanism for AODV (CQAG-AODV) in which RREQ forwarding rate is tuned to the signal strength (RSS) of received RREQ packet. RREQs are rebroadcast with higher probability if they are received along good quality links and with lower probability otherwise. CQAG-AODV is modification to the basic gossip protocol of [8] in which the gossip probability is selected on the basis of signal strength.

Gossip (p, 1, x) approach was suggested in our earlier work [16] where x is the received signal strength threshold (RSS_{Th}). i.e. The source node broadcasts RREQs with probability 1, whereas intermediate nodes follow gossip approach (with p = 0.66) for RREQ rebroadcasting. Gossiping is done only after 1 hop and when signal strength is below RSS_{Th}.

CQAG-AODV is extension to above scheme in which gossip probability is made adaptive to the RSS value. When an intermediate node other than destination, receives RREQ from its precursor, rather than blindly forwarding it first checks the link quality (RSS value). If RSS is above predefined threshold ($RSS \geq RSS_{Th} = r * \beta'$), intermediate node forwards it, otherwise uses gossiping approach in which different gossip probabilities are selected on the basis of RSS value experienced. Use of gossip ensures that in adverse channel environments, network is not partitioned and some network connectivity is preserved even if most of the links are weak or of poor quality.

By forwarding lesser RREQs along links that offer poor signal strength as compared to good quality links having higher signal strength, CQAG-AODV reduces the probability of discovering weak paths. Hence majority of paths discovered will be of good signal quality and robust to failures.

V. IMPLEMENTATION

The proposed CQAG-AODV is implemented in Qualnet 4.5 network simulator from Scalable Network Technologies [17]. Although, proposed CQAG-AODV can work with any PHY-MAC layer protocol, in our implementation we have used IEEE 802.11b as PHY-MAC protocol. Qualnet's IEEE 802.11b implementation defines four receiver sensitivity thresholds viz; -83 dBm, -87 dBm, -89 dBm, and -93 dBm for deciding the MAC data rates. CQAG-AODV uses these receiver sensitivity thresholds as RSS threshold (i.e. modified threshold $r * \beta'$ of equation 4) for selecting gossip probability p. For thresholds of -93 dBm, -89 dBm, -87 dBm and -83 dBm, r takes value 1, 2.5, 4 and 10 respectively. The RSS values and corresponding gossip probabilities are summarized in Table I.

TABLE I. RSS BASED GOSSIP PROBABILITY SELECTION

Received Signal Srength (*RSS*) Value	Channel/Link Quality	Gossip Probability
$RSS \geq$ -83 dBm	Best	$p = 1$
-87 dBm $\leq RSS <$ -83 dBm	Good	$p = 0.66$
-89 dBm $\leq RSS <$ -87 dBm	Weak	$p = 0.50$
-94 dBm $\leq RSS <$ -89 dBm	Poor	$p = 0.33$

Using $p = 1$ with -83 dBm as RREQ forwarding threshold, ensures that best signal quality paths are discovered with highest probability. The gossip probability of $p = 0.66$ for good quality links maintains network connectivity although 33% lesser RREQ messages are forwarded. This is because, p value between 0.65 and 0.75 ensures almost all nodes in the network will get the messages ($\theta_1^S(0.65) = 0.95$) [8]. Other lower probabilities are used as an attempt to avoid network partitioning when most of the links are weak or of poor quality. It should be noted that the specified RSS thresholds based on receiver sensitivity thresholds, are specific to IEEE 802.11b standard and need to be modified if other MAC is used (e.g. IEEE 802.11a specifies 8 receiver sensitivity thresholds).

VI. SIMULATION ENVIRONMENT

The Performance of proposed CQAG-AODV is analyzed by simulating a medium sized ad hoc network using Qualnet 4.5 network simulator. Simulation scenario consists of 150 nodes uniformly distributed in a 1000 m^2 terrain. 10 CBR connections are set between randomly selected source-destination pairs. Each CBR connection sends traffic of packet size 512 bytes. The nodes move randomly following random waypoint (RWP) model with minimum speed of 1 m/s. Performance is evaluated by varying offered traffic load and varying mobility speeds of nodes in non-faded and faded environments. Table II gives the detailed simulation parameters.

TABLE II. SIMULATION PARAMETERS

Parameter	***Value***
Number of Nodes and Area	150 and 1000m * 1000m
Node Placement Strategy	Uniform
Simulation Time	3 minutes
Channel Frequency	2.4 GHz
Path Loss Model	Two ray Model
Fading Model	Rician (k=0)
Propagation Limit	-95 dBm
Mobility Model	RWP (pause time = 0 s)
Mobility speed (m/s)	1.25, 2.5, 5.0, 10, 15, 20, 25, 30, 35, 40
PHY / MAC Layer Protocol	IEEE 802.11b
Traffic Load (pkts/s)	4, 8, 12, 16, 20, 24, 28

VII. RESULTS

This section presents the performance evaluation of CQAG-AODV by comparing the results with conventional AODV and our simple RSS based gossip scheme (RSSGAODV) presented in [16]. Performance is evaluated on the metrics of PDR, throughput, end-to-end delay, RREQ forwarding overhead and link breakages. To analyze the performance of CQAG-AODV two set of experiments were performed. Both experiments comprise of same simulation scenario represented in earlier section. In the first experiment, the mobility speed of nodes is varied between pedestrian mobility speeds of 1.25 m/s to very high speeds up to 40 m/s. The speed is initially set to lowest value of 1.25 m/s and doubled every time up to 10 m/s, thereafter it is gradually increased by 5 m/s. The second experiment comprises variation in the offered traffic load. Here the nodes move with a fixed speed of 5 m/s. Traffic load is varied from 4 pkts/s to 28 pkts/sec (i.e. 16 kbps to 112 kbps), incremented in steps of 4 pkts/sec every time. These experiments are repeated for Rician fading and no fading environments.

A. CQAG-AODV performance in varying Node Mobility Scenario

The objective of this experiment is to analyze the ability of proposed CQAG-AODV to handle channel quality fluctuations arising from node mobility. Figures 1 to 5 show the results of different performance metrics in no fading environment. It can be seen that for mobility speeds between 10 to 25 m/s, performance of CQAG-AODV is the same as that of conventional AODV and RSSGAODV, whereas it is improved for very low and very high speeds (below 10 m/s and above 25 m/s). This is due to degraded signal strength experienced by the nodes at these speeds. At these speeds a given node approaches the limiting communication radius (coverage) with respect to its neighbors. On average, CQAG-AODV offers reduction in link breakages by 5.45% and number of RREQs forwarded by 19.88% as compared to conventional AODV.

Under Rician faded environments CQAG-AODV outperforms conventional AODV at all speeds; and RSSGAODV at speeds above 25 m/s and below 5 m/s as seen in Figures 6 to 10. The average PDR is improved by 6% and link breakages reduced by 9%, with 17.19% lesser number of RREQs being forwarded than AODV. This is a consequence of good quality links selected in the route discovery phase. Links contributing to the path, survive fading effect at higher mobility speeds and thus link breakages are reduced.

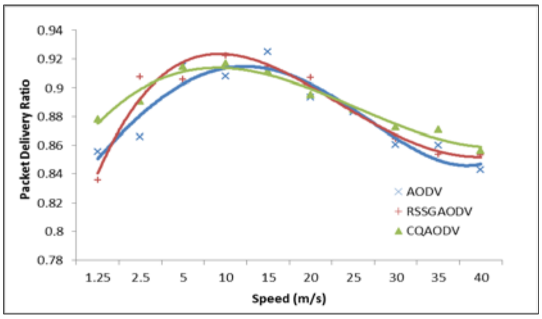

Fig. 1. Packet Delivery Ratio Vs Speed (No Fading)

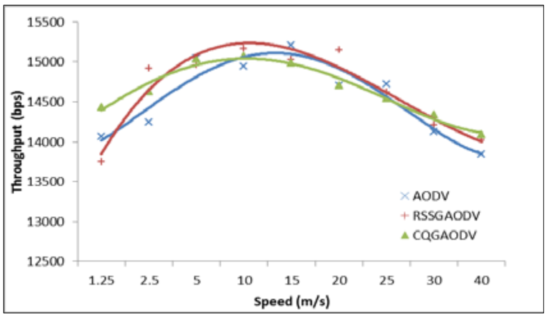

Fig. 2. Throughput Vs Speed (No Fading)

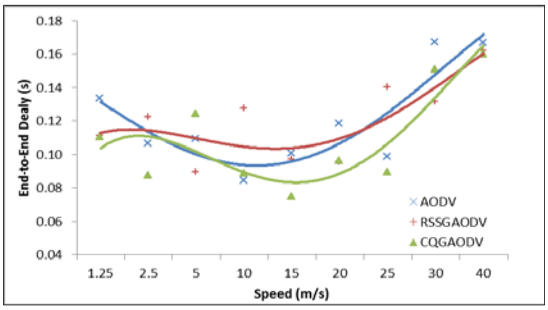

Fig. 3. End-to-End Delay Vs Speed (No Fading)

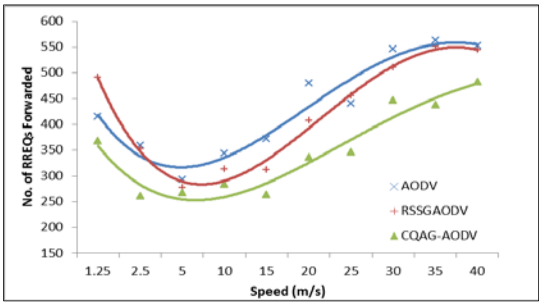

Fig. 4. RREQs Forwarded Vs Speed (No Fading)

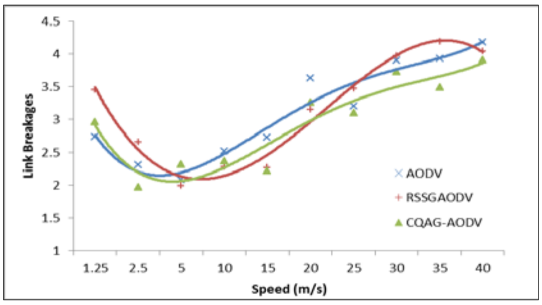

Fig. 5. Link Breakages Vs Speed (No Fading)

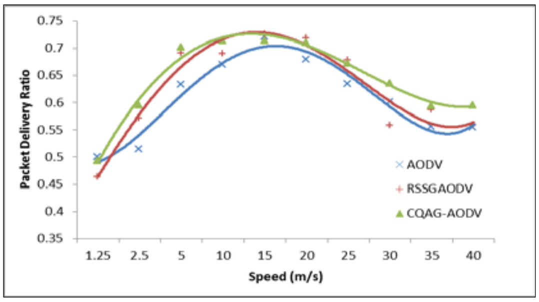

Fig. 6. Packet Delivery Ratio Vs Speed (Rician Fading)

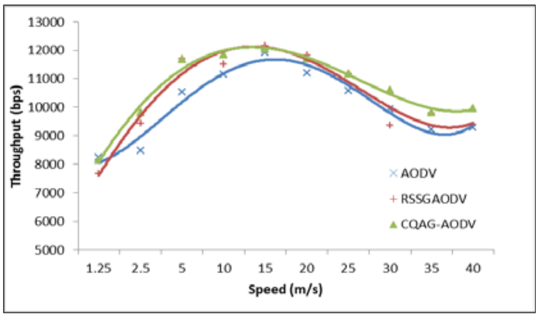

Fig. 7. Throughput Vs Speed (Rician Fading)

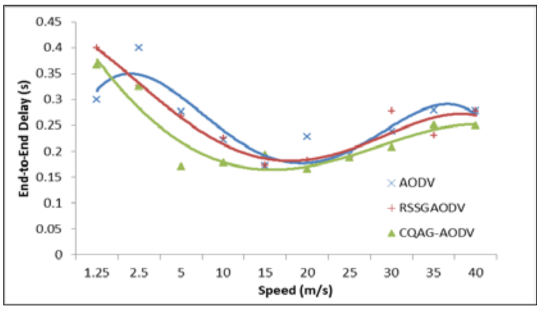

Fig. 8. End-to-End Delay Vs Speed (Rician Fading)

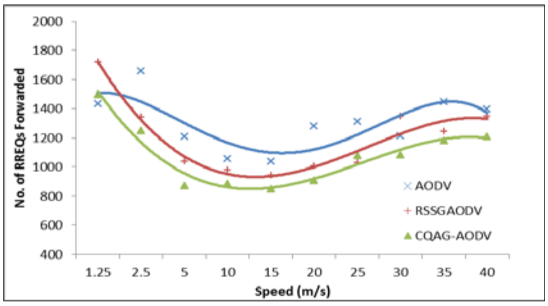

Fig. 9. RREQs Forwarded Vs Speed (Rician Fading)

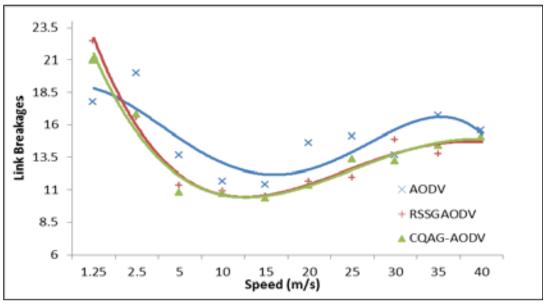

Fig. 10. Link Breakages Vs Speed (Rician Fading)

B. CQAG-AODV performance in varying Traffic Load Scenario

The objective of this experiment is to analyze how well CQAG-AODV handles the offered traffic load. The offered traffic is varied from 4 pkts/s to 28 pkts/s, by an increment of 4 pkts/s each time. Proposed CQAG-AODV outperforms AODV and RSSGAODV on all performance metrics; PDR, throughput, end-to-end delay, link breakages and number RREQs forwarded (Figures 11 to 15). As the offered traffic load is increased above 16pkts/s, the packet delivery ratio of AODV starts degrading due to bandwidth constraints of the channel and increased interference. CQAG-AODV offers better PDR and throughput than AODV, since reduced RREQ broadcasts result in vacating portion of bandwidth which can be used to carry user data traffic. Although there is no explicit interference control mechanism in CQAG-AODV, the selected high signal strength links display higher SINR and thereby reduce the adverse effect of interference.

In scenarios with no fading as compared to AODV, CQAG-AODV improves the PDR by 25%, and reduces the link failures by 19.50% with 32.69% lesser RREQs being forwarded.

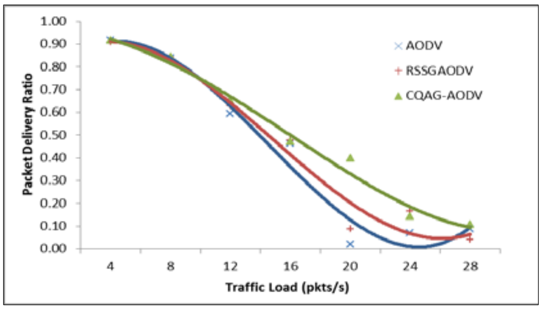

Fig. 11. Packet Delivery Ratio Vs Traffic Load (No Fading)

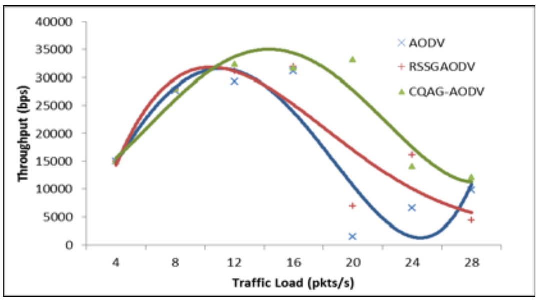

Fig. 12. Throughput Vs Traffic Load (No Fading)

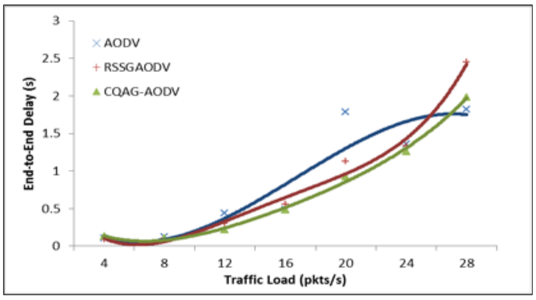

Fig. 13. End-to-End Delay Vs Traffic Load (No Fading)

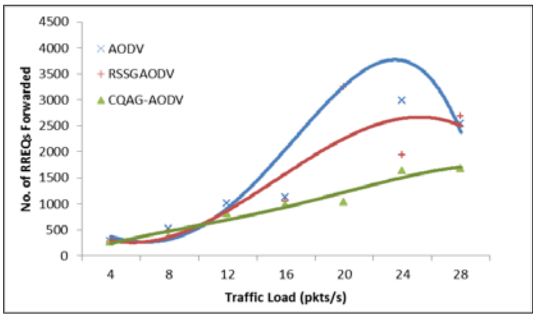

Fig. 14. RREQs Forwarded Vs Traffic Load (No Fading)

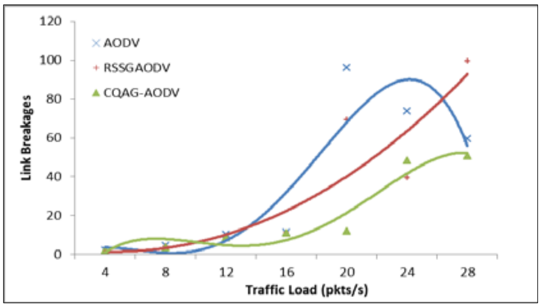

Fig. 15. Link Breakages Vs Traffic Load (No Fading)

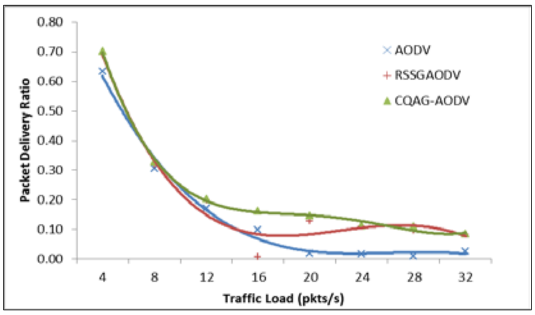

Fig. 16. Packet Delivery Ratio Vs Traffic Load (Rician Fading)

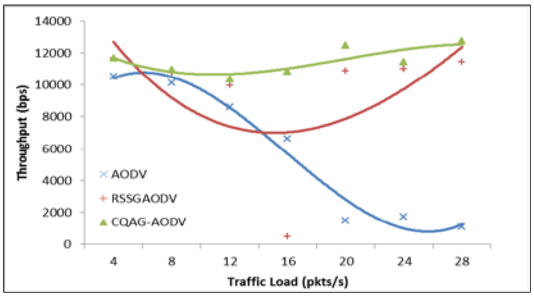

Fig. 17. Throughput Vs Traffic Load (Rician Fading)

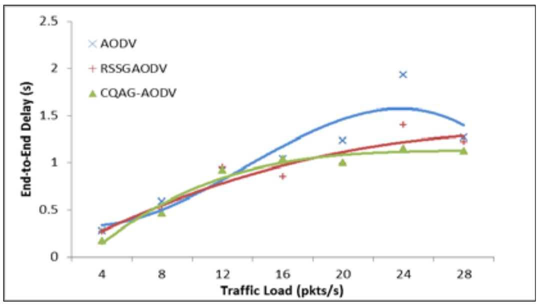

Fig. 18. End-to-End Delay Vs Traffic Load (Rician Fading)

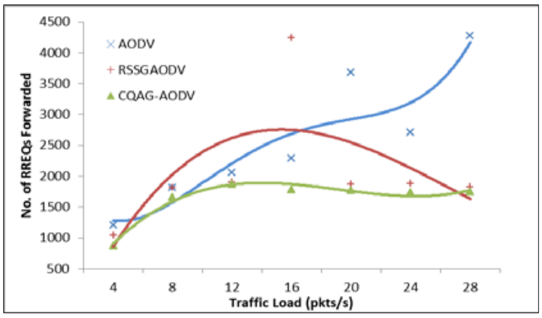

Fig. 19. RREQs Forwarded Vs Traffic Load (Rician Fading)

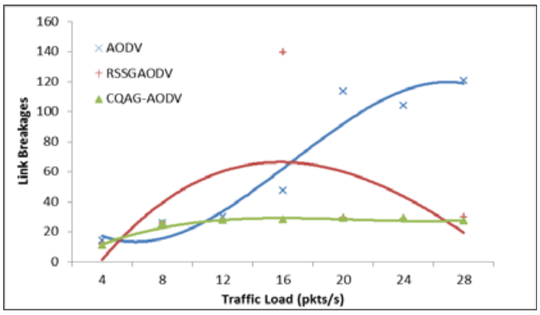

Fig. 20. Link Breakages Vs Traffic Load (Rician Fading)

Under Rician fading, the PDR is improved by 48.11% and link failures are reduced by 42.63% with 30.71% lesser RREQs being forwarded. The performance of CQAG-AODV is slightly better than RSSGAODV since it requires lesser number of RREQs to be forwarded during route discovery than RSSGAODV.

VIII. CONCLUSION

This paper addressed the "broadcast storm" problem that adversely affects the capacity of ad hoc networks. Channel Quality based Adaptive Gossip flooding mechanism for AODV (CQAG-AODV) was proposed, that utilizes the channel quality at physical layer in the routing decision. CQAG-AODV is essentially a cross layer design based probabilistic approach, in which the RREQ forwarding probability is tuned to channel quality of physical medium. RSS is taken as the measure of channel quality and incorporated in the route discovery procedure to decide RREQ forwarding probability of intermediate nodes. Our proposed scheme attempts to discover good quality paths by forwarding more RREQs along strong links as against weak links and thereby improve network performance. CQAG-AODV is implemented in Qualnet simulator and its performance is evaluated for various metrics. Simulation results show that CQAG-AODV addresses the "broadcast storm" problem by reducing the RREQ rebroadcast, also it reduces the link failures since the discovered routes offer high signal strength. CQAG-AODV outperforms conventional AODV on all network metrics for mobility speeds between 1.25 m/s to 40 m/s and also for all offered traffic loads between 4pkts/s to 28pkts/s (16 kbps to112 kbps) in both faded and non-faded environments. However, the improvement is significant when the channel is severely faded.

We are aware that the work presented here is limited to performance comparison of proposed solution with conventional AODV only. More comprehensive treatment is still required to present the proof of concept. The performance of CQAG-AODV needs to be compared with other similar solutions available in the literature so as to highlight the novelty of our contribution. This will be carried out in next phase of our research.

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