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IXLDA: Integrated Cross-Layer Design Approach for Performance Optimization in MANET

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Abstract: In this study, we present an Integrated Cross-layer Design Approach (IXLDA) to enable smart interactions between Transport, Network, Medium Access Control and Physical layers. This approach jointly enhances the data rate adaptation, link quality prediction, routing mechanism and congestion control to realize significant gains in the overall performance of the network. We implant our IXLDA in AODV routing protocol and the new cross-layer AODV (XL-AODV) protocol is simulated using Network Simulator (NS-2). The performance of XL-AODV is compared with non-optimized traditional routing protocols based on three well-known performance metrics. The mean packet delay of the proposed algorithm is 21.86% lesser than basic AODV and 8.10% lesser than M-AODV. Indeed, the average throughput improvement of XL-AODV is about 26.67% higher than basic AODV and 17.70% higher than M-AODV. The substantial improvement in the Packet Delivery Ratio (PDR) achieved by XL-AODV is 8.80% compared to AODV and about 3.32% compared to M-AODV.

Key words: AODV, congestion control, cross-layer design, link quality prediction, rate adaptation, RSS calculation, routing

INTRODUCTION

A Mobile Ad hoc Network (MANET) is one of the most evolving communication technologies which allow mobile users to communicate without pre-established base station. It is a peer-to-peer, self-configuring network of sovereign mobile nodes. The peers of this network can be traced ubiquitously within the coverage area irrespective of their fluctuating topographic position and would be able to move to a required location randomly. The communication between nodes can be achieved in a hop-by-hop fashion.

The substantial proliferation of real time applications such as interactive web browsing, multimedia streaming, Voice-over-IP (VoIP) and high throughput file transfers or email demand different Quality of Service (QoS) guarantees. In order to realize an effective and lucrative technology for future wireless communication, network architects and service vendors need to care about the performance optimization with stringent QoS requirements. QoS is defined as a set of services guaranteed by the network to its users. The QoS assurance depends on some constraints known as throughput, packet loss rate, delay, reliability and fluctuation in packet delay (jitter). Recently, researches on MANET gained incredible interest and popularity because of the following issues it enforces to the network applications (Zhang *et al*., 2005):

- Different real time applications demand very diverse QoS constraints. For example, applications such as VoIP, audio/video broadcasting and video conferencing are highly delay sensitive, but are able to abide by a certain level of error rate (Chen *et al*., 2004). Some applications such as web browsing, email and telemetry are not delay-sensitive, but require hundred percent error free transmissions
- There is no central administrator in MANET to synchronize the inherent functionalities of the arbitrarily moving wireless nodes
- Real time applications are frequently hampered by interference, packet drop, delay and jitter due to signal fading and multipath effect in the wireless medium (Babich *et al*., 2005)
- Frequent link breakage and limited bandwidth make communication in MANET particularly challenging (Wu *et al*., 2009)

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- The mobile devices are power constrained. Reducing the energy budget without degrading QoS is a real challenging issue in MANET
- Network security is a critical concern since wireless links are susceptible to snooping

In view of the aforementioned issues, it is very difficult to satisfy a specified level of QoS in MANET. Most of the techniques proposed for performance optimization in MANET relay on inflexible layering principle which diminishes designing complexity, establishes interoperability and facilitates simple and rapid implementations. Nevertheless, conventional layering architecture restricts the overall performance of the network due to the deficiency of coordination between non-adjacent layers. Moreover, it is not efficient enough to meet the expected QoS assurances for real time applications as synergistic interaction among non-adjacent layers is not allowed. The traditional layered architectures TCP/IP (Leiner *et al*., 1985) and Open Systems Interconnect (OSI) model (Bertsekas *et al*., 1992) are mainly designed for wireline networks and allow only direct communication between adjacent layers via well-defined interfaces. The major shortcoming of this conventional concept is that it is very rigid and does not provide any flexibility for a dynamic environment. Though the layering architecture has been serving the networking designers and service providers for the past three decades, it could not follow the evolution of more challenging real time applications with strict QoS demands (Gavrilovska and Prasad, 2006). For performance optimization, we require a protocol architecture that allows data sharing between different layers is used to boost the system wide performance (Shakkottai *et al*., 2003).

Of late, several cross-layer approaches have been designed to overcome the restrictions in layered architecture. Cross-Layer Design (XLD) relies on any violation or modification of the sharp boundaries of traditional layered architecture. The violation of layering principles includes unification of more than one layer, establishment of novel interfaces and facilitating interaction between various protocol stacks (Srivastava and Motani, 2005). This new paradigm implements stack wide interdependencies and hence enables us to distribute useful information throughout the stack. Recent researches show that careful exploitation of XLD yields a high possibility of optimization and better end-to-end performance gain by smart interactions between non-adjacent layers. Hence, it is the best choice for dynamic real time environment to realize certain decisive impact on the network performance such as QoS assurances, energy conservation or adaptation based on service contract and so forth. The XLD may be realized by either assimilating activities of various layers in a particular protocol or just creating smart interaction across different layers. The former case argues for reduced overhead and complexity by preventing redundancy of information and network activities. It enables us to integrate various factors within a protocol and to develop a flexible cross-layer design. The latter case provides a richer inter-layer harmonization to handle network dynamics and other external factors. Verikoukis *et al*. (2005) provide the taxonomy of cross-layer parameters shared among different layers. For the sake of convenience, four main classes of such parameters are given as:

- Channel State Information (CSI) such as Received Signal Strength (RSS), physical position information, mobility parameters, the collision level, channel fading and modelling, etc. (Taranto and Wymeersch, 2013)
- Generic QoS-related attributes include acceptable delay, required bandwidth, PDR, the bit error rate, reliability and jitter (Chen *et al*., 2004). These metrics can be utilized by various layers in protocol stack
- Network traffic parameters include the type of traffic information of the transmission rate inter-arrival time of packets, data segmentation, etc.
- Resource information includes multi-user scheduling, the battery exhaustion rate, buffer-space, resolution, type of antennae used, etc.

Through cross-layer designs, the information extracted from the physical layer about the channel conditions is used to tune the activities of higher layers (Shakkottai *et al*., 2003). Indeed, the upper layer protocols may gain the potential advantages from this prior knowledge about rapid variations in channel conditions. Likewise, higher layer QoS limitations and service demands are interpreted as the protocol behaviours at the lower layers. For instance by utilizing the transport layer information, it is possible to implement rate adaptation, forward error control mechanisms and queueing policies at lower layers. Motivated by this, we develop a new integrated cross-layer design to allow smart communications between Transport (TRANS), Network (NET), Medium Access Control (MAC) and Physical (PHY) layers that cooperatively enhances the data rate adaptation, link quality prediction, routing and congestion control to promote the overall system performance.

Related works on cross-layer design: Many researchers have proposed numerous cross-layer approaches that implicitly or explicitly break up the boundaries of layered architectures. Most of the studies emphasize on joint optimization across PHY and MAC layers. Only a limited number of works consider upper layer communications to interpret the application level performance requirements into well-defined optimization mechanisms.

Shakkottai *et al*. (2003) discuss the issues of cross-layer approach where the inherent channel state information of the PHY and MAC layer is shared with upper layers to deliver efficient methods for utilizing scarce network resources and applications over the Internet. They propose a XLD for supporting data services in multiuser ad hoc networks (Shakkottai *et al*., 2003). Likewise, Liu *et al*. (2008) suggest a cross-layer cooperative (CoopMAC) protocol to enable interaction between MAC and PHY layers (Liu *et al*., 2008). The CoopMAC protocol comprises of a convincing framework that gains a benefit of the PHY layer integrating in the receiver and delivers a synchronized medium access between nodes. By exploiting spatial diversity and coding gain, the proposed protocol considerably outdoes the conventional IEEE 802.11 focusing on network throughput and packet latency.

Chen *et al*. (2006) propose a cross-layer design to cope with inter-layer communication across TRANS, NET and link layers for congestion control, routing and scheduling through dual-based decomposition algorithm. They use multi-commodity now variables and backpressure signals to define sending rate and resource allocation correspondingly. Then, they propose an extended dual algorithm to tackle the multi-user wireless channel. The authors verify the robustness of the proposed scheme by assessing its performance with respect to an ideal reference system.

Oh and Chen (2009) develop a cross-layer design based on multichannel MAC protocol with Time Division Multiple Access (TDMA) for a reliable delivery of H.264 encoded video streams. The proposed framework is centred on two major modules to design multichannel MAC protocol. In the first module, Maximum Latency Rate (MLR) is considered as the quality measure to categorize the video trafic. The traffic with the lower value of MLR from the PHY layer is considered as a better link quality in MAC layer. In the second module by correlating the knowledge of MAC layer utilization and buffer size in NET layer, they achieve a considerable enhancement in the performance of congestion aware routing protocol.

Xia *et al*. (2006) introduce a new technique for XLD in MANET. They exploit Fuzzy Logic System (FLS) to achieve cooperation across application, data link and PHY layer. The success rates of received packets, ground speed of mobile terminals and packet latency are considered as antecedents for the FLS. During coherent time (a certain epoch of time), Adaptive Modulation and Coding, transmission power, retransmission delay and rate control decision are considered as the metrics for packet transmission. After this epoch, the output of FLS adjusts these metrics dynamically based on their current values. The experimental results show that using the FLS based XLD provides a superior QoS delivery and energy efficiency.

Remya *et al*. (2015) develop an Energy efficient Multipath Routing protocol with an Adjustable Sleeping window (EMRAS) by implementing two algorithms using cross- layer design. The Slow Start Exponential and Liner Algorithm (STELA) increase the energy efficiency of the network by adjusting the sleeping window when there are no network activities. When there is some network activity, Power and Delay aware Multipath Routing Protocol (PDMRP) selects an energy efficient shortest path (Remya *et al*., 2015). The authors also concluded that the EMRAS increases the remaining energy of the nodes by 85.36% and decreases the total energy consumption by 35.63% without sacrificing the QoS parameters of the network.

Navaratnam *et al*. (2008) investigate the influence of channel contention on the behaviour of the TRANS layer. They introduce a novel Link Adaptive Transport Protocol (LATP) to increase the QoS metrics of video streaming applications. The LATP utilizes cross-layer interaction to achieve efficient load control in the TRANS layer for end-to-end flows. According to the knowledge of channel contention gained from the MAC layer, the LATP regulates the transmission rate at the TRANS layer. Experimental results reveal that the LATP provides an efficient mean to increase the QoS performance measures and fairness for real time applications with strict performance constraints.

Ramachandran and Shanmugavel (2008) discuss the necessity of cross-layer design approaches for 4th Generation (4G) mobile networks and beyond. They propose and validate three cross-layer designs among PHY, MAC and NET layers. Their first cross-layer design makes use of RSS information to estimate the minimum required power for packet transmission. They utilize the RSS in their second scheme to calculate the link loss and to thwart the asymmetric communication links. Their third design proposal utilizes RSS information to select stable and reliable paths by observing signal strength to determine whether the neighboring node is sufficiently nearer to the source node or not.

MATERIALS AND METHODS

Motivation of research: From the extensive investigation, we can make the point that many proposed MANET implementations benefited from cross-layer decisions and cross-layer designs are unavoidable in modern networks. The existing approaches often succeed in revealing the benefits of XLD. These approaches offer separate solutions for QoS provisioning, rate adaptation, link breakage, computational overhead, energy consumption and congestion. To the best of our knowledge, there is no end-to-end solution for the above disputes in an unpredictable network environment with modern real time applications. The problems of the existing cross-layer designs are summarized as follows:

- The congestion avoidance algorithms in existing XLDs exploit local link information. However, it is no longer adequate to interpret fluctuating network conditions such as link failure, node failure, topology change, etc
- The existing XLDs are expensive and provide increased design complexity and overhead for unpredictable topology changes due to randomly moving mobile nodes
- As mentioned above, there is no XLD proposed to leverage the potential benefits of all the layers

The fundamental goal of this study is to develop a cross-layer design, not only to promote the overall performance of the network, but also to accomplish a richer interaction between various layers more transparently. Research, described here integrates and controls multi-layer network parameters across different layers in a synchronized manner.

Integrated cross-Layer Design Approach (IXLDA): This section elaborates the Integrated cross-Layer Design Approach (IXLDA) which provides a combined solution for rate adaptation, link quality prediction, optimal route discovery and congestion control. This proposed approach deals with QoS constraints including average throughput, PDR and packet latency. In our proposed work, PHY, MAC, NET and TRANS layer are cooperated closely to harmonize their actions as shown in Fig.1. The main contributions of this study are as follows:

- A mechanism to estimate RSS of the received packets and the remaining energy of the node is developed at PHY layer
- Systematic assimilation is provided between the Dynamic Rate Adaptation Module (DRAM) and Link Quality Prediction Module (LQPM) to share their estimated information. Based on channel state information obtained from PHY layer, DRAM determines the optimal data transmission rate in MAC layer. In order to accomplish maximum performance by avoiding frequent packet loss under fluctuating channel conditions, DRAM adjusts the data rate dynamically

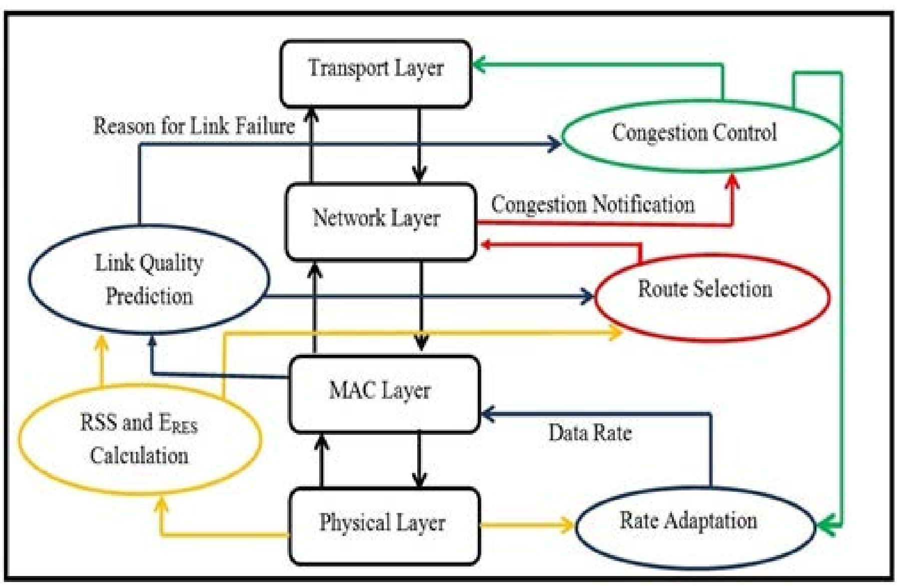

Fig. 1: Integrated cross layer architecture

- LQPM in MAC layer uses RSS information from physical layer to predict the quality of the communication link and its lifetime. The poor quality links having lower signal strength and lower lifetime as compared to threshold values are discarded for packet propagation. LPQM also determines the reasons for link failure and send this information to the upper layers to perform routing and congestion control
- In MANET, loss of link connectivity may arise due to poor channel quality, mobility, congestion and node failure. According to the information extracted form PHY and MAC layer, our Route Discovery Module (RDM) can minimize the routing overhead by estimating whether the reason for packet loss is congestion or node failure and this module rediscovers a new energy efficient path. For this purpose, the routing protocol selects nodes with maximum residual energy and link with maximum lifetime
- Based on information from MAC layer, if the reason for the packet loss is congestion, then TRANS layer implements congestion control algorithms
- The proposed cross-layer approach is embedded in the Ad hoc on demand Distance Vector (AODV) routing protocol with required modifications and our XL-AODV is simulated using NS-2

Estimation of CSI at physical layer

RSS calculation: On receiving every packet, the PHY layer is responsible for estimating the signal strength of the received packet and this important quality metric can be accessed at the top layers. The value of RSS varies with radio wave propagation models, transmission power, the distance between sender and receiver and the antennas gain. In our simulation, the Two-ray ground reflection approximation model is considered and the power of received signal can be measured by Eq. 1. For the sake of simplicity, the noise and fading are not considered in our simulation:

$$P_r = \frac{P_s G_s G_r Hs^2 Hr^2}{d^4 L} \quad (1)$$

Where:

P_r	=	Received signal strength
P_s	=	Transmitted power
G_s and G_r	=	The gains of sender and receiver antenna correspondingly
H_s and H_r	=	The heights of both antennae correspondingly
d	=	The geometrical separation between sender and receiver
L	=	The loss factor of the medium (in our simulation L = 2)

It is assumed that P_s, H_r and H_s are constant, the ground is flat and Omni directional antennas (height of 1.5m and with unity gain in all directions) are used. So, the Eq. 1 can be simplified as follows:

$$P_r = \frac{(P_s K)}{d^4} \quad (2)$$

where $K = (G_s.G_r.H_s^2.H_r^2)/L$ is a constant. Equation 2 indicates that the received power P_r is inversely proportional to d^4. Whenever a node desires to transmit information, it enables the AODV protocol by flooding the Route Request (RREQ) packet to the adjacent nodes and the Route Reply (RREP) packet is received from the intermediate nodes via the shortest route and then registers it in their routing table about the next hop through which the packets are required to be propagated. On receiving the RREQ packet the physical layer of receiver node estimates its RSS value. RSS should be used to know whether the signal of the examined channel is strong enough or not. The receiving node calculates the path loss (P_{loss}) experienced by the received packet as shown in Eq. 3:

$$P_{loss} = P_r - P_s \quad (3)$$

The minimum sufficient power required to transmit the packets is P_{min} such that it should be received on the other node which is determined by Eq. 4:

$$P_{min} = X(P_{loss} + \beta) \quad (4)$$

Where:

P_{loss}	=	The path loss of the channel
β	=	The threshold value of signal strength
X		The multiplication factor (In our simulation, the value of β is selected as -93dbm and X is selected as 4)

Two nodes can establish the connection between them if the following condition given in Eq. 5 is satisfied:

$$P_r \geq P_{min} \quad (5)$$

Estimation of the remaining energy: In MANET, the estimation of energy consumption of a mobile node for various network operations is a complicated task. Energy in mobile nodes continuously exhausts due to networking functionalities (e.g., carrier listening, transmitting and receiving packets, etc.), energy related computation of protocols, activities associated with traffic load (i.e., packet generation and buffering) and channel contention. In this research, all the nodes are initialized with 100 J of energy which will be consumed in transmission and reception of the data packets and also utilized for control actions to be performed at the node level. The balance energy is calculated in every 10 sec. Packets may be generated by the same node or received for the forwarding purpose from the neighbouring nodes. The residual energy is the energy left out at a node after a finite time. The total energy consumption of ith node at time t ($E_i(t)$) in a contention-free channel can be calculated as follows:

$$E_i(t) = \sigma N_F E_b + \sigma N_R E_b + E_{i\_idle} + E_{i\_sleep} \quad (6)$$

Where:

N_F = No. of forwarded packets
N_R = No. of received packets
σ = The packet size in bits
E_b = The energy consumption per bit
E_{i_idle} = The energy consumption of node in an ideal mode
E_{i_sleep} = The energy consumption in sleeping mode

The residual energy of the ith node can be calculated at any time by subtracting the consumed energy from the initial energy of the node as shown in Eq. 7:

$$E_{i\_RES}(t) = \text{Initial energy} - E_i(t) \quad (7)$$

In this research, on receiving every RREQ message the node calculates its remaining energy. If the residual energy of the node is greater than or equal to the predefined value, then it processes the RREQ otherwise the request is rejected and the node is considered as "dead" and not designated as a path for further transmission. After computing RSS and residual energy, the P HY layer transfers this information to upper layers to optimize the performance. The MAC layer uses this information to predict the status of the link and NET layer exploits this information for optimal route selection.

Channel aware dynamic rate adaptation at MAC layer: Rate adaptation is a procedure to regulate the data bit-rate dynamically according to channel conditions. In MANET, contention-free MAC schemes (e.g., IEEE 802.11) have been extensively used with Distributed Coordination Function (DCF) where the neighbouring hops are competing for the shared wireless medium. The DCF exploits Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol to synchronize the channel access and to combat the drawbacks associated with exposed-terminal and hidden-terminal problems (Zuquete, 2008). The DCF allows nodes to send data frames only if the medium is idle for a definite time period which is called as the Distributed Inter-Frame Space (DIFS). The nodes are restricted to communicate until the carrier becomes idle. When the medium is currently busy or turns into busy for the period of the DIFS due to another transmission, the sending node automatically delays its transmission and then it falls into the exponential back off with the initial size of the back off window. Hence, every node has a buffer space where it queues the incoming packets until the medium becomes free to access.

If the medium is free then the sender first sends a control frame, namely Request-To-Send (RTS) to the destination. After a successful reception of RTS frame, the destination node postpones its transmission for a small duration (i.e., Short Inter-Frame Space (SIFS)) and then sends a Clear-To-Send (CTS) frame to the sender of RTS, confirming that the RTS frame has been correctly received. After a SIFS interval, the sender node transmits its data frame to the receiver as shown in Fig. 2. After receiving RTS, the receiver estimates the data rate to be used by the sender and piggybacks that information to the sender with the CTS frame. The sender's MAC layer can access this information and use it to regulate its data rate for successive transmission. The sender's PHY layer receives the CTS and as a side effect MAC can estimate the quality of the link from the receiver to the sender. The intermediate nodes will update this information in their Network Allocation Vector (NAV) and preserve that information as long as the current transmission gets successfully completed. According to the current utilization and quality of the channel, a node can de?ne its data rate for every packet. If a node has a higher quality channel, then it will send at high data rate and vice versa. The objective of the proposed Dynamic Rate Adaptation Module (DRAM) in our work is to select the most appropriate data rate according to the present channel conditions. On receiving a route request from the sender, every receiver node estimates the available bandwidth according to the current channel utilization. Available bandwidth is defined as the maximum throughput which can be used for the data transmission between the two nodes. The effective utilized bandwidth ($B_{utilized}$) is the number of packets in bits, transmitted during channel occupation time at MAC layer:

$$B_{utilized}(bps) = \frac{\Sigma_0^{Nt}(\sigma)}{\Sigma_0^{Nr}(T_{co})} \quad (8)$$

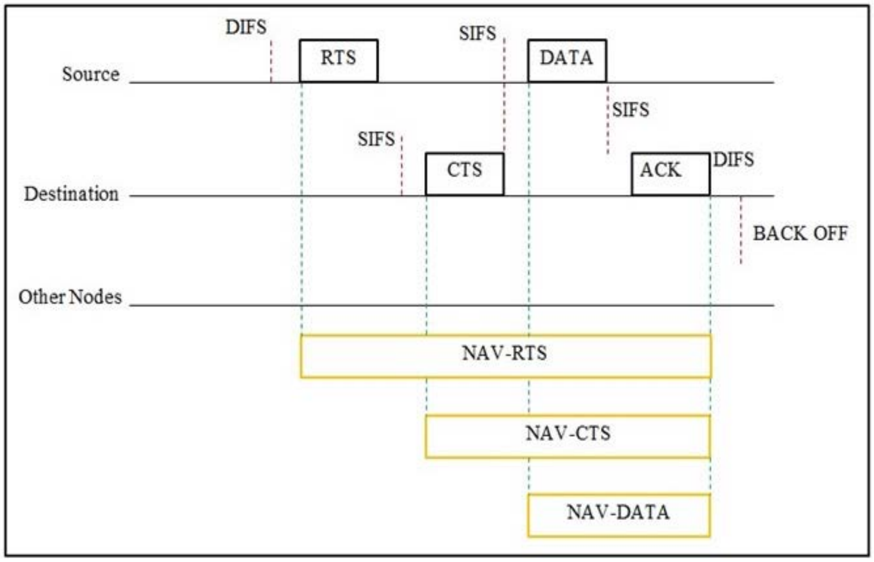

Fig. 2: Channel access and data delivery process at MAC layer

Where:

σ = The packet length in bits
N_r = No. of the received packets
N_t = No. of the transmitted packets
T_{co} = The channel occupation time

It is the time interval measured from the instant when a frame starts competing for carrier access to the instant at which the whole data is acknowledged. T_{co} is calculated in MAC layer as follows:

$$T_{co} = T_{busy} + T_{cw} + T_{const} \quad (9)$$

Where:

T_{busy} = The reserved channel time taken for RTS-CTS handshake and it can be derived from the network allocation vector.
NAV-RTS NAV-CTS = The idle period for the node which and listens to the RTS/CTS exchange
T_{cw} = The duration of the Contention Window (CW) for a transmission opportunity
T_{const} = The constant time which comprises of several components as shown in Eq. 10

Whenever a node observes the access collision, it increases the CW size until its pre-defined value is reached; clearly, the size of CW can interpret the collision condition more precisely:

$$T_{const} = T_{DIFS} + T_{PHY\_Header} + T_{MAC\_Header} + 3T_{SIFS} + T_{ACK} + T_{Back\_off} \quad (10)$$

Where:

T_{DIFS} = The duration of distributed Inter-Frame Space
T_{PHY_Header} = The transmission period of the PHY header
T_{MAC_Header} = The transmission period of the MAC header
T_{SIFS} = The duration for Short Inter-Frame Space
$T_{backoff}$ = The duration for executing back off procedure to queries the channel again

If B_{max} is the maximum data rate supported by the network, then:

$$D_{avail} = B_{max} - B_{utilized} \quad (11)$$

After calculating the available bandwidth, the receiver sends this information to the destination. On receiving available bandwidth information, the sender can make a decision on how many data packets should be admitted at that time and regulates its data rate accordingly. On the other hand, the intermediate nodes which receive the packet will update and preserve bandwidth information in their NAV.

Link quality prediction at MAC layer: In MANET, the mobile terminals are assumed to have a fixed range of transmission. The destination node which is placed inside the sensing range of the source node can receive the packets. This study determines the link availability between two nodes. In a dynamic network, mobility of the terminal is one of the major causes of path breaks and can lead to packet loss subsequently. The MAC layer predicts

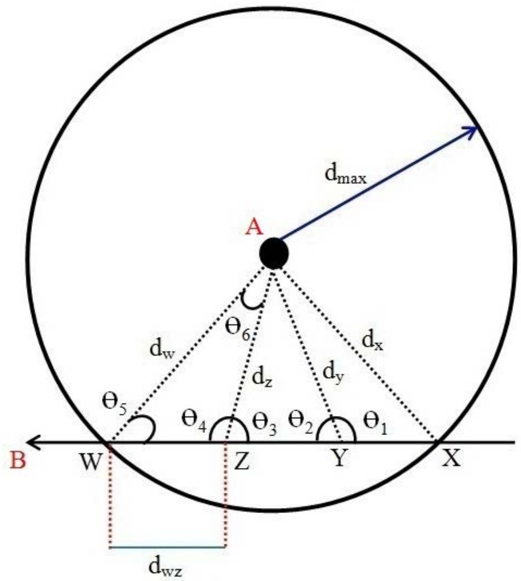

Fig. 3: Illustration of relative movements of nodes

the quality of the active link and its lifetime based on the RSS information extracted from the PHY layer. By using RSS values of three latest packets from a node, the receiver's MAC layer decides whether to select the node as the communication link or not.

Figure 3 illustrates the relative movement of nodes A and B, where d_{max} is the maximum transmission range of node A (in our experiment d_{max} = 50 m). The RSS information and timestamp in the neighbouring table of three latest received packets from a particular node can be used to decide whether that node is approaching or leaving the transmission range of the source node. If the received RSS values of a node at different time vary with excellent to low, then the transmitting node is considered as moving away from the transmission range.

Consider A and B are sender and receiver nodes correspondingly. Before transmitting any packet to its neighbouring node B, A wants to calculate the lifetime of link between itself and node B. Assume that the node A is static and B is moving at a relative speed S and a particular direction as shown in Fig. 3.

The current position of node B is Z. Point X and Y are the positions of B while it sent messages with RSS information to A. The approach only needs three registered RSS values of each neighbour which lessens the space complexity and the calculation overhead. Point W is the estimated position at which the node B moves out of the sensing range of node A. At this point, node B enters into a critical state and node A should find an alternate route by enabling the route discovery mechanism to forward its packets. The δt_1 and δt_2 are the inter-arrival time of three recent packets with RSS values received from B. The distance d_{wz} and the relative speed of terminal S are used to estimate the link lifetime. In LQPM, HELLO packages of AODV are exploited to record RSS values with their time stamps in the neighbouring table. To track the network topology in the dynamic scenario, HELLO packages are broadcast periodically, but the inter-arrival time of the HELLO packages are not identical, since these intervals are jittered by the routing process to mitigate interferences. Thus the mechanism does not need any extra control messages and the format of the messages need not be modified since only the RSS information is required. Hence, the proposed prediction module does not consume any extra energy from the node. Figure 3, we can derive the cosine value of angle θ_1 and θ_2 as follows:

$$\theta_1 + \theta_2 = 180° \quad (12)$$

$$\text{Cos}\theta_1 = -\cos\theta_2 \quad (13)$$

$$\frac{(S\delta t1)^2 (dy)^2 - (dz)^2}{2dyS\delta t1} = \frac{-(S\delta t2)^2 (dy)^2 - (dx)^2}{2dyS\delta t2} \quad (14)$$

where d_X, d_Y and d_Z are the distance from node A to the three locations of node B at various time. The distance between any two nodes can be calculated from Eq. 1, so:

$$d = 4\sqrt{\frac{Pt \times Gt \times Gr \times ht^2 \times hr^2}{Pr \times L}} \quad (15)$$

The relative speed of node B can be estimated as follows:

$$S = \sqrt{\frac{dx^2 \times \delta t1 + dz^2 \times \delta t2 - dy^2(\delta t1 + \delta t2)}{(\delta t1 + \delta t2) \times \delta ti \times \delta t2}} \quad (16)$$

The calculated relative speed value from Eq. 16 is stored locally. In order to detect speed changes, stored speed values are approximately taken as an integer. To predict the link lifetime between the nodes, the procedure of estimating d_{WZ} is given below. We can derive the following relationship from ΔAWZ:

$$\frac{dw}{\sin\theta 4} = \frac{dz}{\sin\theta 5} = \frac{dwz}{\sin\theta 6} \quad (17)$$

Equation 17, the value of θ_5 can be estimated as follows:

$$\theta 5 = \sin^{-1}\left(\frac{dz.\sin\theta 4}{dw}\right) \quad (18)$$

Since, three sides of ΔAWZ are already known, the value of θ_4 and θ_3 can be obtained by the following equations:

$$\theta 4 = 180° - \theta 3 \tag{19}$$

$$\theta 3 = \cos^{-1}\left(\frac{dz^2 + dxz^2 - dx^2}{2dz \times dxz}\right) \tag{20}$$

form Fig. 3, it is clear that $\theta_6 = \theta_3 – \theta_5$ and θ_4 = 180°- θ_3, then, we can calculate the value of d_{wz} as follows:

$$dwz = \frac{dw \times \sin\theta 6}{\sin\theta 4} \tag{21}$$

therefore, link lifetime (T_L) can be calculated from the following equations:

$$T_L = \frac{dwz}{S} \tag{22}$$

$$T_L = \frac{dw \times \sin\theta 6}{S \times \sin\theta 4} \tag{23}$$

The calculated RSS values, residual energy of node and link lifetime are used at the NET layer of the calculating node to predict whether the loss of link between A-B is likely to happen or not. When a link is expected to break in the near future, then the source will rediscover a new route for its further communication. The main objective of using the RSS value, residual energy and link lifetime as the cross-layer parameters is that the routing decision has to be made efficiently at the NET layer by judging the route with the node having high RSS and high T_L. By using link quality and its lifetime, the MAC layer identifies the reason for the link failure and sends this information to the TRANS layer to enable congestion control procedures. If the neighbouring node is sufficiently nearer to the source node and their link lifetime is enough to receive packets but there is packet loss is interpreted as the congestion of the receiving node.

Improved route discovery at network layere: In our research, the residual energy and link lifetime are considered as the metrics for route acquisition. The selected path between source and destination will change every time as it hinges on the remaining energy and link lifetime. For convenience, a path between source and destination is expressed as follows:

$$R = \{(i_0, i_1)...,(i_{h-1}, i_n)\forall(i_k, i_{k+1}) \in L \tag{24}$$

Where:

$i_0, i_1....i_n$ = The nodes lying along an active route
i_0 = The sender node
i_n = The receiver node
L = The set of links

It is assumed that there are many routes between the sender and receiver. The remaining energy of route R is described as:

$$E_{route} = Min\{(E_{i0}, E_{i1}...E_{ih-1}) \tag{25}$$

The route with maximum remaining energy is considered as the appropriate route. The best route is carefully chosen from existing routes ($R_{max} \in R$) as:

$$R_{max} = Max\{(E_{i0}, E_{i1}...E_{ih-1}) \tag{26}$$

Improved route discovery at network layer: Congestion is characterized by delay and loss of packets in delivery. Transmission Control Protocol (TCP) in the transport layer can support the mechanisms of flow and congestion control for reliable data transmission. According to the information obtained from the MAC layer, TCP determines whether the loss is due to congestion or not and then acts accordingly. When congestion is sensed, a backpressure signal CON, warning sign in this case, need to be set as 1 and propagated to downstream nodes. The time function of transmission rate is given in Eq. 27:

$$B_{int} = \begin{cases} B_{int}(t) + \Delta b & B_{int} < B_u, CON = 0 \\ B_{int}(t) & B_{int} = B_u, CON = 0 \\ B_{int}(t)/2 & CON = 1 \end{cases} \tag{27}$$

where B_{int} and B_u are the initial and upper threshold value of data rates respectively. The sender initially (i.e., t = 0) sets its transmission data rate, B_{int} (t), to a small value. If congestion has not been detected for at least one round trip time and on receiving of each ACK, TCP increases its data rate additively (i.e., B_{int} (t) + Δb).

If the data rate approaches its maximum threshold value and observing that there is no congestion (CON = 0), then TCP transmit data at maximum rate. If there is a congestion notification received from the lower layer (CON = 1), TCP performs multiplicative decrease and the congestion window is halved (i.e., $B_{int}(t)/2$) in response to the congestion. The congestion notification signal also sends to the MAC layer to adjust the date rate.

RESULTS AND DISCUSSION

A comprehensive simulation study is carried out in a Network Simulator tool (NS-2) to analyse the efficiency of our proposed XL-AODV protocol. Recall that XL-AODV (i.e., AODV with cross-layer benefits such as rate adaptation, link quality prediction, congestion control and improved route discovery) considers RSS, residual

Table 1: The NS-2 simulation parameters

Parameters	Values
Number of nodes	50
Grid topology	500×500 m
Rate of control signal	1 Mbps
Data transmission rate	2 Mbps
Length of the packet	512 bytes
Transmission power	100 mW
Carrier frequency	2 GHz
Traffic	CBR
MAC protocol	IEEE 802.11g
Transport protocol	TCP
Routing protocols	AODV, M-AODV and XL-AODV

energy, link quality and link expiration time for the route establishment and utilizes MAC layer adaptation for the congested nodes. To study the impact of mobility and network size on the performance of the XL-AODV, M-AODV and the basic AODV protocols, the Two-ray ground reflection approximation model is employed. Simulations are executed for 1200 sec for three rounds at varying values. The parameters along with the corresponding values that are considered to carry on the simulation are listed in the Table 1. Extension of AODV to adapt our cross-layer design.

As we previously stated, Ad hoc on demand distance vector routing protocol is reactive in nature; so routes are built only on demand. AODV uses hop-by-hop routing and performs routing in two phases: path discovery and path maintenance. Whenever a node (initiator) desires to transmit data packets to an unknown destination (receiver), the initiator starts its route discovery phase to locate the receiver node. The initiator node disseminates RREQ message to all its immediate neighbours. Every intermediate node either response RREQ by transmitting a RREP message when it has routing information for that receiver or propagating the RREQ to its neighbours when it has no valid routing information. For efficient routing, the HELLO packets are periodically propagated to ensure the bidirectional connectivity between the communication nodes.

In modified AODV (M-AODV) (Khan *et al*., 2014) an intermediate node can create an adaptive reply decision for an incoming demand. This is achieved by adding two more messages to the conventional AODV protocol. If there is a loss of link connectivity due to arbitrary mobility of nodes during data transmission, a Route Error (RERR) message is transmitting to the originator of the request message through intermediate nodes. As the RERR forwards to the originator, each relay node nullifies routes to that inaccessible receiver. Once the originator gets the RERR, it stops emitting the packets and restarts its path discovery phase. The ACK message must be sent in response to the RREP message. So, M-AODV is the better choice for routing than the conventional AODV protocol.

The proposed cross-layer AODV (XL-AODV) uses AODV for routing with necessary modification. AODV control packages such as RREQ, RREP and HELLO packets are altered to accommodate extra information. In our XL-AODV, the RREQ packet is transmitting with hop count (initially it equals 0), Maximum RSS and required bandwidth. The RSS of the RREQ packet is compared with a threshold value. After this comparison, the receiving node propagates the RREQ packet only if the RSS greater than threshold value, otherwise the packet is dropped. Then, the field of required bandwidth is compared with available bandwidth. The receiving node forwards the RREQ only if the available bandwidth is sufficiently greater than required bandwidth. While dispatching the request, node increments the hop count field in the RREQ by one. Modifications are required in the format of RREP packets to send B_{avail} and CON notification. HELLO packages are modified to hold link lifetime.

Extension of AODV to adapt our cross-layer design: The effectiveness of the proposed approach is evaluated using comparison experiments in terms of following well-known performance metrics.

Mean end-to-end delay: Delay specifies the average amount of time taken to transmit an information packet from an emitter node to an intended destination. It is measured as duration between the generation of information packet and the reception of an Acknowledgement (ACK) for the corresponding packet. The mean delay along the path is equal to sum of queueing delay, contention delay and transmission delay.

Average throughput: Average throughput is the number of information bits passing through the network in a particular time period.

Packet Delivery Ratio (PDR): This metric shows the level of received packets at the destination. It is defined as the fraction of the number of delivered packets to the receiver node over the number of generated packets at the emitter node. The lesser delay, higher PDR and higher throughput indicate the superior performance of protocol.

Effect of node mobility: In our first simulation scenario, we investigate the impact of the speed of nodes on the performance of AODV, M-AODV and XL-AODV protocols. The number of nodes is selected as 50. The transmission range of each node varies between 20 and 50 m and we assume that there is a symmetric link between any two nodes if their geometric distance is smaller than the transmission range. Then, we change the

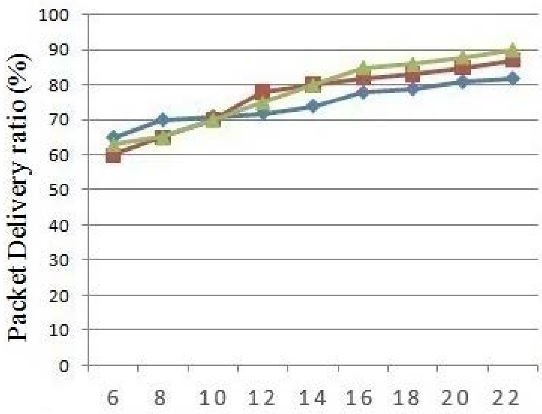

Fig. 4: Node mobility vs. packet delivery ratio

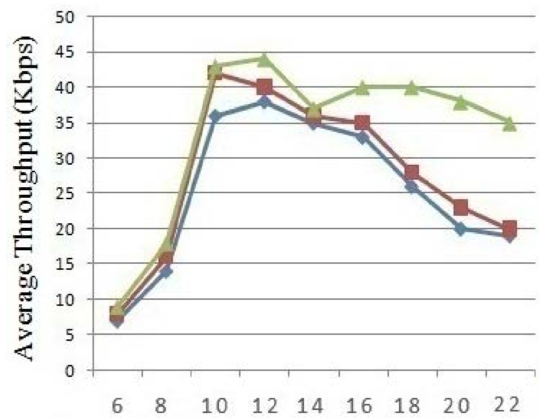

Fig. 5: Node mobility vs. average throughput

start-up speed of the devices from 4-25 m sec^{-1}. We present the obtained results against various mobility conditions.

The packet delivery ratio of our XL-AODV is more as compared to M-AODV and AODV as shown in Fig. 4. As mobility of the nodes grows the possibility of link breakage increases for all protocols. Therefore, the packet drop rate also increases gradually. Nevertheless by taking residual energy and link lifetime in to account, XL-AODV has the maximum packet delivery ratio as compared to AODV. In XL-AODV, only a lesser amount of packets is discarded using its tight inter-layer cooperation which results in the good PDR. XL-AODV delivers a greater percentage of originated data to the final destination effectively. The low packet delivery fraction of AODV and M-AODV may be explained by the aggressive route caching built into these protocols. Further, it is observed that the performance of XL-AODV is consistently uniform.

It can be seen from Fig. 4 that XL-AODV clearly outdoes other two protocols, particularly at high mobility. The average PDR of AODV is 68.7% and M-AODV is 77.8% whereas for XL-AODV is 79.35%. The enhancement realized by our protocol, compared to AODV is about 15.42% and compared to M-AODV 1.93%. This behaviour is described by the fact that XL-AODV diminishes the probability of contention by reducing the occurrence of collisions. Furthermore, this is a direct result of familiarizing the MAC layer information in XL-AODV. Moreover, owing to the congestion aware effect activated by the proposed XL-AODV, it shows the higher performance as compared to the basic AODV and M-AODV protocols. This indicates the stability and reliability of the proposed protocol and its capability to adjust itself to varying mobility conditions.

Figure 5 shows the results obtained for the average throughput characteristic of routing protocols against various mobility conditions of the nodes. In the case of high mobility, M-AODV and XL-AODV improves the overall throughput of the network. This is because of the number of link failures in M-AODV and XL-AODV is decreased as compared to basic AODV. In AODV, the number of hops in the path fluctuates between low and high values, due to frequent link failures which make AODV to perform a new route discovery process. The average throughput of AODV is 24.5 packets sec^{-1} and M-AODV is 26.6 packets sec^{-1} whereas for XL-AODV is 33.6 packets sec^{-1}. Indeed, the improvement is about 37.14% higher than basic AODV and 26.3% higher than M-AODV.

The delay of communication increases with node speed for all routing protocols as given in Fig. 6. In case of XL-AODV, it discovers the congested free route by exchanging inter-layer state information. Hence, the probability of congestion is reduced which results in lesser mean delay.

Figure 6 illustrates the simulation results gained for mean delay in milliseconds under various node speeds. It is observed from the graph, for low mobility, the mean delay of M-AODV and XL-AODV is more or less similar. With an increase in mobility, performance of AODV and M-AODV is worse as mobility leads route errors and to re-establishment of the route discovery process and hence higher delay is experienced. Conversely, XL-AODV incurs the least delay of communication with respect to node mobility. It is evident from the graph that the mean delay of AODV is 0.69 sec and M-AODV is 0.60 sec whereas for XL-AODV is 0.56 sec which is 18.16% lesser than basic AODV and 5.42% lesser than M-AODV.

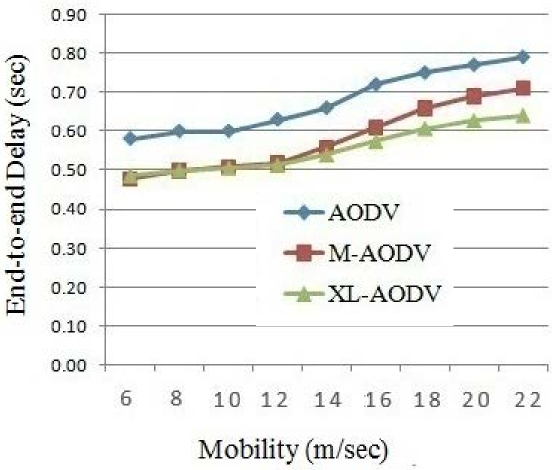

Fig. 6: Node mobility vs. end-to-end delay

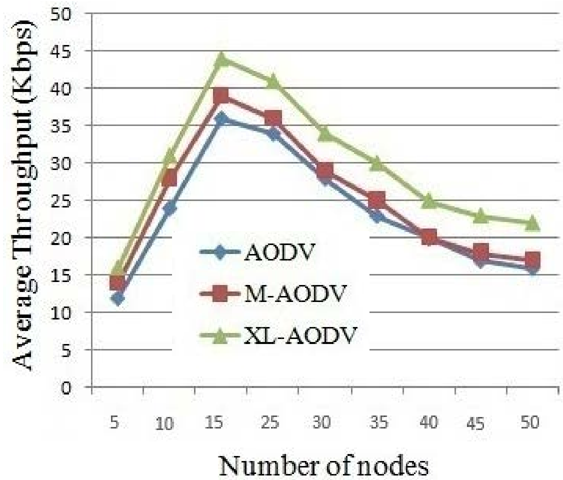

Fig. 8: Number of nodes vs. average throughoutput

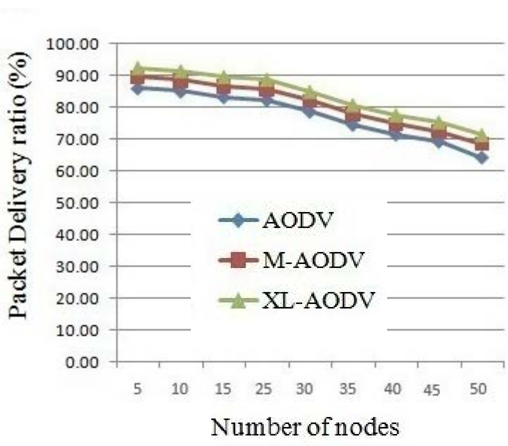

Fig. 7: Node mobility vs. packets delivery ratio

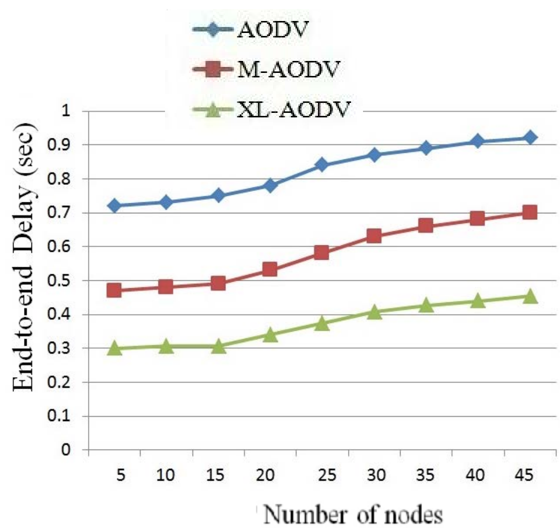

Fig. 9: Number of nodes vs. end-to-end delay

Effect of number of nodes: In the second simulation scenario, we discuss the impact of the number of nodes on the performance of studied protocols. The corresponding results are presented in Fig. 7-9.

Figure 7 plots the results obtained for PDR versus different network sizes. The general trend of all curves is a decline in PDR with the size of the network. This happens because when the topology gradually increases, a greater possibility of access conflicts and channel contention.

The results exhibit that our XL-AODV perform superior than other two existing protocols. The PDR of AODV is 77.21% and M-AODV is 80.77% whereas for XL-AODV is 83.45%. The enhancement accomplished by XL-AODV compared to AODV is about 8.08% and M-AODV is about 3.32%. M-AODV and XL-AODV show the similar trend at low node density. On the other hand, when the number of node gradually increases, the performance of XL-AODV is on the higher side as compared to M-AODV protocol. This is because of XL-AODV can deliver more packets by decreasing the channel contention and the access collision.

A similar result can be observed in Fig. 8 where the average throughput in against the number of nodes is depicted. It is noticed that XL-AODV has maximum throughput as compared to other two protocols. The average throughput of AODV is 23.33 packets sec^{-1} and M-AODV is 25.11 packets sec^{-1} whereas for XL-AODV is 29.56 packets sec^{-1} which is 26.67% higher than basic AODV and 17.70% higher than M-AODV.

Figure 9 shows the mean delay in milliseconds with respects to the number of nodes for the three protocols. The delay experienced by a packet increases with the number of nodes. It can be seen that, the trend of the increase in delay is almost same for AODV, M-AODV as well as our XL-AODV. However as the increase of the number of nodes, the delay experienced by XL-AODV is more stable and significantly lower than that of other two protocols. The average end-to-end delay of AODV is 0.82 sec and M-AODV is 0.70s whereas for XL-AODV is 0.64 sec which is 21.86% lesser than basic AODV and 8.10% lesser than M-AODV. The obtained results show how efficiently XL-AODV adapts to oscillations in traffic load. The proposed integrated cross-layer design approach is implanted in basic AODV and several performance parameters are rigorously selected and utilized to demonstrate its effectiveness. Our proposal enables nodes with better characteristics to take part in the routing process. Subsequently, the possibility of route failures due to mobility is decreased and the forwarding overhead is minimized considerably. It can be observed from the analysis presented above that the XL-AODV provides a better QoS enhancement as compared with other two protocols in the literature.

CONCLUSION

The proposed cross-layer design approach provides an integrated solution for rate adaptation, link quality prediction, routing and congestion control. The conclusion of the research can be made on the observation of the graph obtained from actual run time simulation. Comparative performance evaluation work is organized between XL-AODV and existing non-optimized protocols using NS-2. The performance of XL-AODV is evaluated against M-AODV and AODV by means of performance criteria such as mean delay, average throughput and PDR. The mean delay of the proposed algorithm is 21.86% lesser than basic AODV and 8.10% lesser than M-AODV. Indeed, the average throughput improvement is about 26.67% higher than basic AODV and 17.70% higher than M-AODV. It has been verified that XL-AODV significantly outdoes both basic AODV and M-AODV based on PDR. Our XL-AODV provides 8.80% better PDR compared to AODV and 3.32% better than M-AODV. Finally, these performance results convincingly demonstrate that the proposed cross-layer design is superior to both basic AODV and M-AODV routing protocols. In the future, we can consider the application layer for the cross-layer design.

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