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An Optimized Cross-Layer Design Approach for Power Management in Mobile Ad-hoc Network

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Abstract—As portable mobile devices gain popularity, the need for Mobile ad-hoc network (MANET) is becoming unavoidable in the wireless-dominated next-generation communication system.MANETs with conventional layered architecture does not efficiently support real-timemediatransmission since it has large resource requirements andhard timing constraints for data delivery.The cross-layer designs (XLD) differ from a conventional layered architecture where each layer of the architecture performs autonomously. The wide range of different intelligent cross-layer applications reveals its importance. In this paper, we propose an Optimized Cross-Layer Design (OXLD) approach to provide systematic assimilation between the PHY, MAC and NET layer to share their locally available information efficiently. OXLD provides a combined solution for link availability prediction and optimal route discovery. This will result in a substantial performance improvement in terms of QoS constraints including average throughput, PDR and packet latency.

Keywords — cross-layer design; MANET; QoS; XLD; challenges;

I. INTRODUCTION

The proliferation of mobile computing devices and penetrating advanced technologies in computer networking has spawned demands for infrastructureless and fast deployable mobile networks. Such networks are called Mobile Ad-hoc Networks (MANET). It is a peer-to-peer, self-configuring network of sovereign mobile nodes. The peers of this network can be found ubiquitously within the coverage area irrespective of their fluctuating topographic position and would be able to move to a required location randomly.MANETs are employed for severallife- and mission-critical applications. Anapplication is said to be life-critical whose execution failure might lead to loss of human life or severeharm to the environment (e.g. military strategicprocesses, search and disaster relief management, etc.).Failureof mission-critical applications can lead toa slight service interruption in the system that is not disastrous (e.g., virtual classrooms, teleconferencing, multi-user games, etc.)[1].

The architecture of communication networks issplit into layers to decrease the processing complexity and regulatethe flow of information to be transferred. Conventionally, the protocol stack has been envisioned to deal with complex problems by dividing into independent layers. The description and responsibilities of each layer are stated explicitly and autonomously, whereasapplication specifics and internal factors are concealed to the other layers. Every layer in thisarchitecture is isolated from the others with the exception of producing output to and getting input from neighbouring layers with little information about the status of the network [2].

Based on the direction of the information flow upward/downward, each layer performs its own task by getting inputs from the layer below/above and delivers the output above/below. The layering principle reduces designing complexity and facilitates simple and rapid implementations. The traditional layered architectures, five layer TCP/IP [3] and seven-layer OSI [4] reference models, are remarkably fruitful for wired networks and allow only direct communication between adjacent layers via standardized interfaces. The interface specifies which service primitive (operation) that the lower layer makes available to the layer above it.

The key benefit arising from these layered architectures is modularity to facilitate interworking and enhanced performance of transmission protocols. The most important deficiency of conventional layered architecture is that it is very rigid and does not provide any flexibility for a dynamic environment. It limits the overall efficiency of the network owing to the deficiency of cooperation between non-adjacent layers. Standardization of layered architecture has allowed rapid implementation of interoperable systems, on the other hand severely restricted the competence of the entire system, owing to the deficiency of harmonization between layers. For performance tuning, a protocol architecture that allows data sharing between different layers is used to boost the system-wide performance [5]. Furthermore, it is not efficient enough to satisfy the expected service quality for multimedia applications, as synergistic communication between non-adjacent layers is not permitted.

Demand for Quality-of-service (QoS) assurances in real-time applications is pushing the investigators to bring revolutions in MANETs. QoS is a set of services guaranteed by the network to its users. The absence of the central administrator, frequent link breakage and limited bandwidth make communication in MANET particularly challenging. In view of these issues, it is very difficult to satisfy a specified level of QoS in MANET. Most of the techniques proposed for performance optimization in MANET rely on inflexible layering principle, which diminishes designing complexity, establishes interoperability and facilitates simple and rapid implementations. Nevertheless, conventional layering architecture restricts the overall efficiency of the network owing to the deficiency of cooperation between non-adjacent layers.

Of late, several cross-layer approaches have been designed to overcome such restrictions. Cross-layer techniques enable the user to break up or modify the sharp boundaries of traditional layered architectures. They allow different layers to interchange state information or to synchronize their operation to provide a decisive effect on the performance of the network. Protocols utilize the interlayer information to adjust their behaviouraccordingly. The interdependency across different layers presents the benefit of explicit layer cooperation, to handle meagre performance of communication channels and nodes, high BER, energy conservation, QoS, etc. This new paradigm implements stack wide interdependencies and hence enables us to distribute useful information throughout the stack.

Though there are several approaches to XLD, they can be categorized into evolutionary and revolutionary cross-layering [6]. An evolutionary, otherwise called as weak cross-layering approach provides communication between nodes at various layers; it thus denotes the collaborationidea of the layered architecture to take account of “non-contiguous” communications. The revolutionary or strong cross-layering approach provides the combined design of the algorithms employed within any entity at any level of the protocol stack; in this case, individual characteristics associated with the different layers can be lost owing to the cross-layering optimization. Potentially, revolutionary XLD may offer greater performance at the expense of reducing feasible implementation scenarios and increasing cost and complexity.

Modern 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 the dynamic real-time environment to realize the certain decisive impact on the network performance such as QoS assurances, energy conservation, or adaptation based on the service contract and so forth.

As stated above, 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 functionalities. It enables network designers to integrate several parameters 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. Some motivating XLD solutions have been projected in literature the [7-9], together with some critical works addressing the hazards of an uncontrolled XLD leading to unsynchronized communication, network dynamics, and system uncertainty.

To realize a preferred optimization goal, there is a necessity to share locally available information between various layers which is called as state information. The XLD utilizes this interlayer information to adjust their performance respectively and this will increase the overall performance of the network. Verikoukis et al. provide the taxonomy of cross-layer parameters shared among different layers [10]. For the sake of convenience, four main classes of such parameters are given below:

- Channel state information (CSI) like physical position information, received signal strength (RSS), mobility parameters, collision level, channel fading, modelling etc. [11].
- Generic QoS related attributes include acceptable delay, required bandwidth, PDR, BER, reliability, and jitter. These metrics can be utilized by various layers in the 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, 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 [5]. 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 behaviors 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, a new integrated cross-layer design is developed to allow smart communications between NET, MAC, and PHY layers to link lifetime prediction and route selection for promoting the overall system performance.

The rest of this paper is organized as follows: The following Section provides substantial relevant approaches aiming to support XLD over MANETs. The overall structure of the proposed OXLD architecture is discussed in Section III. Adaptive link layer techniques are discussed in Section IV. The implementation detail of OXLD is explained in Section V.As a final point, we conclude this paper in Section VII.

II. RELATED WORKS

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. The link state information from PHY and MAC layers can be utilized in the NET, TRANS and APP layer for designing the optimization models, particularly for dynamic channel conditions. Only a limited number of works consider higher layer interactions to interpret the application level performance requirements into well-defined optimization mechanisms. In most of the existing system, cross-layer feedbacks are exploited to facilitate propagation of state parameters from higher layers to lower layers or vice versa, however, the conventional layered architecture is conserved.

Shakkottai et al. 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 an XLD for supporting data services in multiuser ad hoc networks [5].

Likewise, Feilu et al. suggest a cross-layer cooperative (CoopMAC) protocol to support interaction between MAC and PHY layers [12]. The CoopMAC protocol comprises of a convincing framework that gains a benefit of the PHY layer integration at the receiver and delivers 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.

Ferrari et al. propose enhancement in AODV protocol by considering the BER of each communication link in the route discovery phase. The modified AODV with power control leads to the choice of the route reducing the overall BER [13].

Power control algorithms in the PHY layer can frequently influence the sending data rate of mobile devices. Xinsheng Xia et al. introduce a new technique for XLD in MANET. They exploit Fuzzy Logic System (FLS) to achieve cooperation across application, TRANS, data link, and the PHY layer. The success rates of received packets, the ground speed of mobile terminals and packet latency are considered as antecedents for the FLS. During the 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 [14]. 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.

Muthumayil et al. propose an Energy based cross-layered AODV (ECL-AODV) as an enhancement of the basic AODV routing protocol [15]. Before sending RREQ message, ECL-AODV checks the residual energy (Eres) of the node. If this Eres is less than a threshold (Eth) value, then that node is not taken into consideration during the route selection phase. If Eres is higher than Eth, it adds its address and the remaining energy in the message and propagates it toward the destination. In this protocol, RTS/CTS handshake occurred after the route discovery and route reply to reserve the selected route so that the energy of the node can be conserved. RTS/CTS handshake consumes reduced energy since this transmission occurs only in the designated route. This protocol achieves improved QoS guarantees in terms of average energy consumption, PDR, transmission latency, and throughput.

Lijun et al. develop an XLD to cope with inter-layer communication across the link, NET and TRANS layers for scheduling, routing and congestion control through dual-based decomposition algorithm [16]. They use multi-commodity flow 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.

Navaratnam et al. 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 [17]. 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 discuss the necessity of cross-layer design approaches for fourth generation (4G) mobile networks and beyond [18]. 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 nearby node is sufficiently nearer to the source node or not.

Liu and Singh examine the impact of connection unavailability and network fragmentation issues due to unpredictable node mobility on the behavior of TCP. An Ad-hoc TCP (ATCP) is recommended to increase the throughput of TCP. The ATCP deals with various routing problems such as packet drop due to high BER, variations in the route, network fragmentation, packet rationalization, multi-path routing, and congestion control [19].

From the extensive investigation, the point to be made here is 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. However, there is no end-to-end solution for the disputes in an unpredictable network environment with modern real-time applications. The problems of the existing cross-layer designs are summarized as follows:

- The existing XLDs are expensive and provide increased design complexity and overhead for the unpredictable topology changes due to randomly moving mobile nodes.
- The congestion avoidance algorithms in the 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.
- As mentioned above, there is no XLD proposed to leverage the potential benefits of all the layers.

The objective of this research work is to design cross-layer architecture to stimulate the overall performance of the network and to accomplish an improved interaction across different layers more evidently. The work, described here, integrates and controls multi-layer network parameters across different layers in a synchronized manner.

III. CROSS-LAYER DESIGN APPROACH

This section elaborates the proposed Optimized Cross-Layer Design Approach which provides a combined solution for link availability prediction and optimal route discovery. By using interlayer interaction, OXLD enables different layers to share their locally available information efficiently. This will result in a substantial performance improvement. This approach deals with QoS constraints including average throughput, PDR and packet latency.

3.1 System Architecture

In this proposed work, PHY, MAC, and NET are cooperated closely to harmonize their actions. For the description of OXLD, a simple functional block diagram is given in Figure 1. This OXLD is a hardware independent approach. All modules are software components. Systematic assimilation is provided between the PHY, MAC and NET layer to share their estimated parameters. A mechanism to estimate RSS of the received packets and the remaining energy of the node is developed at PHY layer. Based on state information obtained from the PHY layer, the MAC layer predicts the availability of the communication link and its lifetime. The poor quality links having lower signal strength and a lower lifetime as compared to threshold values are discarded for packet propagation. In MANET, loss of link connectivity may arise due to poor channel quality, mobility, congestion, and node failure. MAC layer determines the reasons for link failure and sends this information to the NET layer to perform routing.

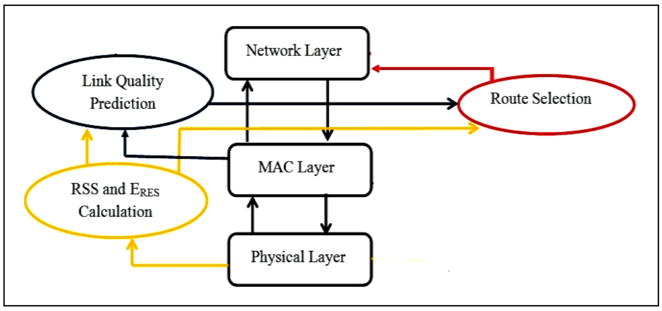


Figure 1: Proposed optimized cross-layer architecture

According to the information extracted from PHY and MAC layer, the route discovery module (RDM) in the NET layer 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 the route with minimum hop count, maximum residual energy and link with maximum lifetime. The proposed cross-layer approach is embedded in the Ad hoc On-demand Distance Vector (AODV) routing protocol with required modifications and XL-AODV is simulated using network simulator NS-2.

3.1 Estimation of state information at the physical layer

The physical layer is responsible for establishing, maintaining, and releasing physical connections between network devices. It plays a very important role in wireless communications due to the challenging nature of the transmission channel. The power consumption of wireless nodes severely relies on the PHY layer. The MAC layer manages wireless resources for the PHY layer and directly impacts overall network performance. Therefore, joint PHY and MAC layers techniques are emphasized to improve wireless energy efficiency.

The PHY layer deals with data transmission over the wireless medium and consists of radio frequency circuits, modulation, power control, and channel coding units, etc. Traditional wireless systems are built to operate on a fixed set of operating points to support the highest feasible PHY rate; hence, they always transmit the maximum allowable power, i.e. no power adaptation. This results in excessive energy consumption for average channel conditions. Hence, a set of PHY layer parameters that influence the system-level energy efficiency and performance should be adjusted to adapt the actual user requirements (e.g. throughput and delay) and environments (such as shadowing and frequency selectivity) to trade off energy efficiency and spectral efficiency.

In OXLD, a mechanism is developed that determines the RSS of the received data packet from each nearby node to decide whether a neighboring node is near enough for successful packet transmission. This protocol exploits the remaining energy of nodes to select the appropriate route based on the energy level of their nodes.

3.1.1 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 the simulation, the Two-ray ground reflection approximation model is considered and the power of the received signal can be measured by the following Equation (1). For the sake of simplicity, the noise and fading are not considered in the simulation.

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

In the aforesaid equation, P_r is received signal strength; P_s is transmitted power; G_s and G_r denote the gains of sender and receiver antenna correspondingly; H_s and H_r are the heights of both antennae correspondingly; d is the geometrical separation between sender and receiver; L is the loss factor of the medium (in the simulation L=2). It is assumed that P_s, H_r, and H_s are constant, the ground is flat and omnidirectional antennas (height of 1.5 m and with unity gain in all directions) are used. So the Equation (1) can be simplified as follows,

$$\mathrm{P_r} = \frac{\mathrm{(P_s.K)}}{\mathrm{d^4}} \qquad (2)$$

where K = (Gs.Gr.Hs2.Hr2)/L is a constant. The Equation (2) indicates that the received power Pr is inversely proportional to d4. 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 (Ploss) experienced by the received packet as shown in Equation (3).

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

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 Equation (4)

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

whereP_{loss} is the path loss of the channel, β is the threshold value of signal strength, and X is the multiplication factor (In the 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 the Equation (5) is satisfied.

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

3.1.2 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 get exhausted 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 work, all the nodes are initialized with 100 Joules 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 remaining energy is calculated every 10 seconds. Packets may be generated by the same node or received for the forwarding purpose from the neighboring nodes. The residual energy is the energy left at a node after a finite time. The total energy consumption of thei^{th} node at time t ($E_i(t)$) in a contention-free channel can be calculated as follows

$$E_i(t) = \sigma.N_F.E_b + \sigma.N_R.E_b + E_{i_{idle}} + E_{i_{sleep}} \qquad (6)$$

where N_F and N_R are the number of forwarded and received packets respectively; σ is packet size in bits and E_b is energy consumption per bit; E_{i_idle} is energy consumption of node in an ideal mode; E_{i_sleep} is energy consumption in sleeping mode. The residual energy of the i^{th} node can be calculated at any time by subtracting the consumed energy from the initial energy of the node as shown in the Equation (7).

$$E_{i_{RES}}(t) = \text{Initial Energy} - E_i(t) \qquad (7)$$

When the network initiates its operation, each node estimates and registers its own percentage of the remaining energy and, after each 't' time units, the node must compare its present energy level ($E_{i\_RES}(t)$) with what has been recorded previously ($E_{i\_RES}(t-1)$). If the value of $E_{i\_RES}(t)$ is less than the predefined value of E_{th} (i.e. threshold energy), then there is a need to recharge the battery otherwise the node is considered as "dead" and not designated as a path for further transmission.

In this proposed work, 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 PHY layer transfers this information to upper layers to optimize the performance. The MAC layer uses RSS information to predict the status of the link and NET layer exploits the residual energy for optimal route selection.

3.2 Estimation of Channel Quality

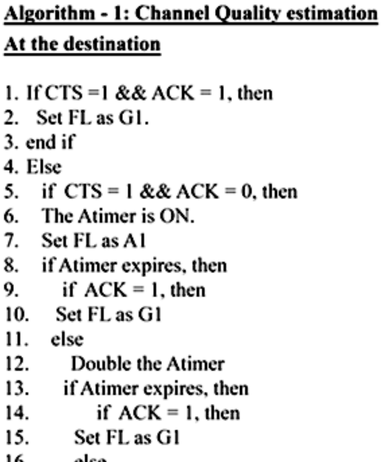
In MANET, contention-free MAC schemes (e.g., IEEE 802.11) have been extensively used with Distributed Coordination Function (DCF), where the nearby hops are competing for the shared wireless medium. The DCF exploits Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol to synchronize the channel access and to combat the drawbacks associated with exposed-terminal and hidden-terminal problems.This protocol assesses the channel condition based on the packet success rate, tested at two levels (i) At the destination and (ii) At each relay node along the route. The sending node has no means to determine the reason for an unsuccessful transmission. The links qualities of destination and relay nodes are independent of each other. Only if the requirements at both the levels are satisfied, the medium is confirmed to be in good state.

At destination

By sharing the two short control frames between a source and a destination, all nearby nodes identify the transmission and backoff during the transmission time advertised along with the RTS and CTS frames. In the channel quality prediction, the CTS and ACK frames are tested at the destination node. According to the results of these frames, the channel is categorized into three states namely GOOD1 (G_1), BAD1 (B_1) and AWAITING1 (A_1). Consequently, a flag (FL) is used to point out the equivalent channel condition. The flag can indicate three values: G_1, B_1 or A_1.

- Check for the CTS frames, which report to the source that the frames are confirmed to be sent.
- Also check for the ACK frames, which is an acknowledgement of successful data transmission.

If both the CTS and ACK packets are received successfully within their time-out duration, then the condition of the medium is designated as GOOD. If a node fails to receive an ACK frame within its time-out duration, then condition of the medium is designated as AWAITING state. If both the frames are not successfully received, then the medium is considered as in BAD state and ultimately the successive transmissions are dropped out.



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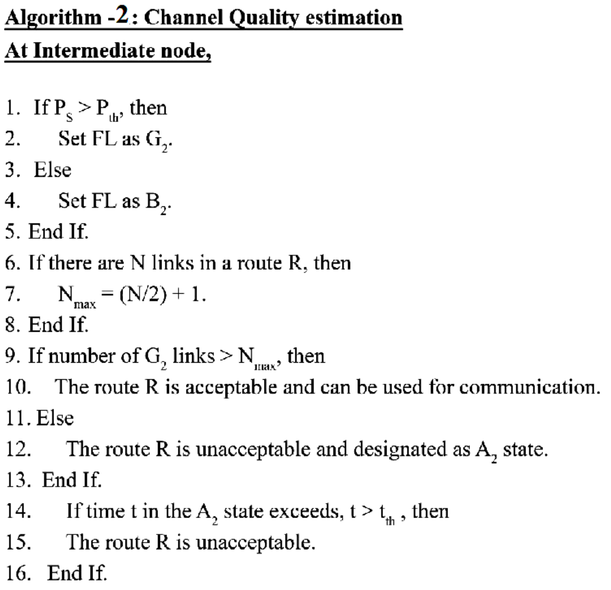
Algorithm - 1: Channel Quality estimation
At the destination

If CTS =1 && ACK = 1, then
  Set FL as G1.
end if
Else
   if CTS = 1 && ACK = 0, then
   The Atimer is ON.
   Set FL as A1
   if Atimer expires, then
      if ACK = 1, then
     Set FL as G1
    else
       Double the Atimer
      if Atimer expires, then
           if ACK = 1, then
        Set FL as G1
```

At Each Intermediate Node

At each Intermediate node, the packet success rate (P_S) is compared with a predefined threshold value (P_{th}) (in this simulation P_{th} = 0.7) in order to estimate the quality of the channel. The packet success rate is defined as the ratio of the number of successful transmissions to the most recent transmissions. If the value of P_s is higher than the predefined value, the link is in good condition with its state designated as GOOD2 (G_2) else the link is considered bad and designated as BAD2 (B_2). As the channel status is validating at each and every node, the variations in channel quality are updated with the exact channel status.

Suppose a route has several links with both good and bad states, then in such cases the route is acceptable only if it comprises maximum number of links with state good or else the route is unacceptable (i.e.) not appropriate for communication and will be preserved in the AWAITING (A_2) state for a certain time period (t_{th}) (in this simulation t_{th} = 150 ms). For example, if there are totally 7 links in a route with 4 of the links in state G_2, then the path is acceptable as the maximum links have G_2 state. Suppose only 3 of the links are in G_2 state, then the route is unacceptable. After the channel status increases and if the maximum number of links in the route have state G_2, then the route is acceptable. Also once the t_{th} value is surpassed, then also the route is unacceptable and is not appropriate for communication.



Algorithm -2 : Channel Quality estimation

At Intermediate node,

```
If $P_S > P_{th}$, then
    Set FL as $G_2$.
Else
    Set FL as $B_2$.
End If.
If there are N links in a route R, then
    $N_{max} = (N/2) + 1$.
End If.
If number of $G_2$ links > $N_{max}$, then
    The route R is acceptable and can be used for communication.
Else
    The route R is unacceptable and designated as $A_2$ state.
End If.
    If time t in the $A_2$ state exceeds, $t > t_{th}$ , then
    The route R is unacceptable.
End If.
```

3.3 Link availability prediction at the 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 section determines the link availability between the two nodes. The MAC layer predicts the availability 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.

3.3.1 Link Failure Due to Mobility in MANET

In a dynamic network, the mobility of the terminal is one of the major causes of path breaks and can lead to packet loss subsequently. Since terminals in a MANET serve as routers for any ongoing packet transmission and have narrow communication ranges, the links are broken and packets are lost.This problem is intensified when a route consists of many such broken links. If any of those links fail, the route breaks, which introduces a sequence of adverse problems and consequences. If the availability of the link can be predicted, the NET layer protocol can exploit this prediction in its route acquisition process to limit its usage, which in turn decreases the packet drop in this link. It is assumed that every link remains available for a limited time, called link lifetime (T_L). The route lifetime (T_R) hinges on the lifetime of links which lie in that route. When the rate of mobility rises, T_L and then T_R reduce accordingly. This affects the packet delivery ratio and throughput adversely.

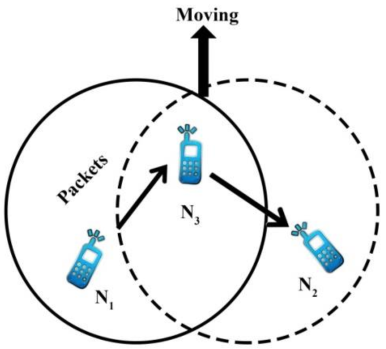


Figure 2: Link failures due to node mobility in ongoing transmission.

For instance, node N_1 is communicating with node N_2 using node N_3 as an intermediate node (router) and N_3 is moving in any direction as shown in Figure 4.3. If N_3 moves out of the transmission rage of N_1 or N_2 or both, the communication link between N_1 and N_2 will fail and some packets of the ongoing communication will be lost. Hence, developing efficient techniques for solving mobility problems in MANET is inevitable.

3.3.2 Determination of link availability time

The duration of link availability among two terminals is boundless for static networks while it varies with mobility in dynamic ad hoc networks. Since the nodes are mobile, link breakage is unavoidable in MANET. As stated in the previous section, link breakages increase packet drop substantially. This section provides an effective means to estimate the duration of connectivity of two neighboring nodes in a route.

Figure 3 illustrates the relative movement of nodes A and B, where d_{max} is the maximum transmission range of node A (in the experiment d_{max} = 50 meters). The RSS information and timestamp in the neighboring 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 from 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 the 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 Figure 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. δt_1 and δt_2 are the inter-arrival time of three recent packets with RSS values received from B.

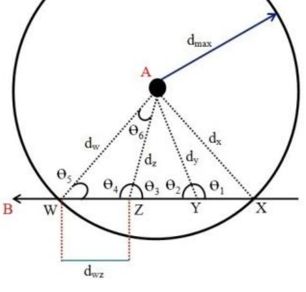


Figure 3: Illustration of relative movements of nodes

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. From Figure 3, the cosine value of angle θ_1 and θ_2 can be derived as follows

$$\theta 1+\theta 2=180° \qquad (8)$$

$$\cos\theta 1=-\cos\theta 2 \qquad (9)$$

$$\frac{(S.\delta t1)^2+(dy)^2-(dz)^2}{2.dy.S.\delta t1}=\frac{-(S.\delta t2)^2+(dy)^2-(dx)^2}{2.dy.S.\delta t2} \qquad (10)$$

whered_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 the Equation (1), so

$$d=\sqrt[4]{\frac{Pt.Gt.Gr.ht^2.hr^2}{Pr.L}} \qquad (11)$$

The relative speed of node B can be estimated as follows

$$S=\frac{\sqrt{dx^2.\delta t1+dz^2.\delta t2-dy^2(\delta t1+\delta t2)}}{(\delta t1+\delta t2).\delta t1.\delta t2} \qquad (12)$$

The calculated relative speed value from the Equation (12) 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. The following relationship can be derived from ΔAWZ

$$\frac{dw}{\sin\theta 4}=\frac{dz}{\sin\theta 5}=\frac{dwz}{\sin\theta 6} \qquad (13)$$

From the Equation (4.17), the value of θ_5 can be estimated as follows

$$\theta 5=\sin^{-1}\left(\frac{dz.\mathrm{Sin}\theta 4}{dw}\right) \qquad (14)$$

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

$$\theta 4=180°-\theta 3 \qquad (15)$$

$$\theta 3=\cos^{-1}\left(\frac{dz^2+dxz^2-dx^2}{2.dz.dxz}\right) \qquad (16)$$

Form the Figure 3, it is clear that $\theta_6 = \theta_3 - \theta_5$ and θ_4 =180°- θ_3, then the value of d_{wz} can be calculated as follows

$$dwz=\frac{dw.\sin\theta 6}{\sin\theta 4} \qquad (17)$$

Therefore, link lifetime (T_L) can be calculated from the following equations.

$$T_L=\frac{dwz}{S} \qquad (18)$$

$$T_L=\frac{dw.\sin\theta 6}{S.\sin\theta 4} \qquad (19)$$

The calculated RSS values, the residual energy of node and link lifetime are used at the NET layer of the calculating node to predict whether the loss of the link between A and 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, then the packet loss is interpreted as the congestion of the receiving node.

3.3.3 Determination of Route Life Time

The route available time (i.e. T_R) is a significant criterion for the proposed algorithm. Every node which lies in a particular route has its own T_L, and the node with the minimum T_L has a greater possibility of disconnecting the route. Therefore, the minimum T_L in any route is T_R. According to the proposed algorithm, the source node transmits the RREQ message with a maximum value in its T_R field (e.g., T_R = 99999 sec.). If any node lies in the route, it compares its T_L with the T_R in the RREQ packet. If $T_L < T_R$, it substitutes the T_R field of RREQ message with its own T_L, or else, it propagates the RREQ message without altering the T_R field. After receiving the RREP, the source computes the net route lifetime (T_{R_net}) as follows

$$T_{R\_net} = T_R - t_{route} \quad (20)$$

wheret_{route} is a mean delay between source and destination, which will be used to estimate the number of packets successfully transmitted from source to destination. The source registers the T_{R_net}, and the t_{route} in the route cache.

3.3.4 Mobility Algorithm

The algorithm used in this research to solve mobility related problems is given in algorithm 3.

3.4 Improved route discovery at Network layer

In the work, the hop count, residual energy and route 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

$$R = \{(i_0, i_1)\ldots, (i_{h-1}, i_n) \quad \forall (i_k, i_{k+1}) \in L \qquad (21)$$

where i_0, $i_1 \ldots i_n$ are nodes lying along an active route; i_0 is the sender node and i_n is the receiver node; L denotes set of links. It is assumed that there are many routes between the sender and the receiver. The remaining energy of route R is described as

$$E_{route} = \mathrm{Min}\{(E_{i0}, E_{i1} \ldots . E_{ih\text{-}1}) \quad (22)$$

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

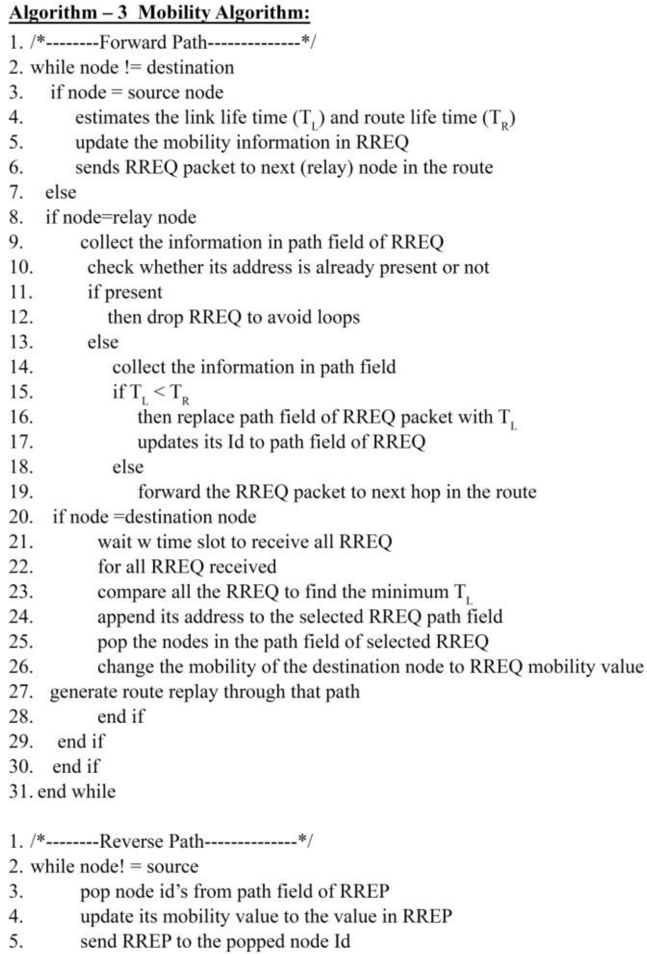
$$R_{max} = \mathrm{Max}\{(E_{i0}, E_{i1} \ldots . E_{ih-1}) \qquad (23)$$

3.4.1 Improved Route discovery algorithm (IRDA)

The proposed algorithm at network layer exploits the values of three quality measures to discover the best route for data transfer: (i) availability of route (ii) Remaining energy of route (E_{route}) (iii) hop count to avoid long and inefficient paths. Extra fields are required in RREQ and RREP packets to account these three measures to each available path. The route selection phase for IRDA depends on two thresholds to compare the available routes. The first one is the hop count threshold (H_{diff_th}), which indicates the maximum difference of the number of hops between two given routes. Another predefined value is E_{th} (threshold energy).

Algorithm 4 illustrates the path selection procedure, where there are three simple conditions. The ShiftToRoute function denotes a shift from the active route to an alternate route. Three conditions filter the paths based on the verdict structures given in Lines 6, 12, and 18. These structures estimate the alternate route (R_{alt}) and classify it as their energy level, comparing it with the current active route (R_{act}). Line 18 indicates the use of E_{th} as a tolerance parameter for the difference that is valid if R_{alt} has less energy. After examining the energy level, the algorithm computes the hop counts and estimates the quality of the links based on route lifetime.

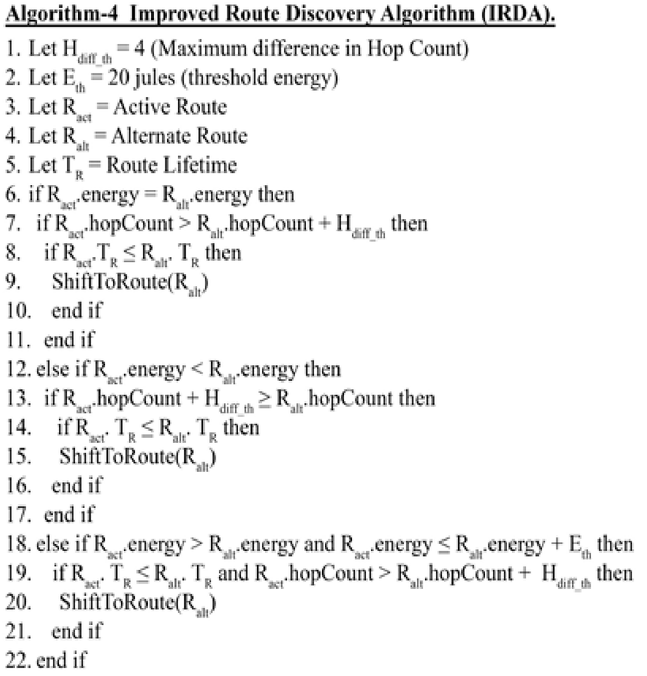
This estimation is presented in Lines 8, 13, and 19, where H_{diff_th} is considered as a threshold. Based on this algorithm, the next stage of the estimation requires only if R_{act} is a route that has more hops (Lines 7 and 13). The condition defined in Line 18 is an exceptional case in the route discovery phase since it examines the cases where R_{alt} has a reduced amount of energy than the active route. In this case, R_{alt} has to substitute R_{act} if the energy variance with respect to the threshold E_{th} and R_{alt} is substantially lesser (Line 19).



Algorithm – 3 Mobility Algorithm:

```
/*--------Forward Path--------------*/
while node != destination
  if node = source node
     estimates the link life time ($T_L$) and route life time ($T_R$)
     update the mobility information in RREQ
     sends RREQ packet to next (relay) node in the route
  else
  if node=relay node
      collect the information in path field of RREQ
       check whether its address is already present or not
       if present
          then drop RREQ to avoid loops
       else
          collect the information in path field
          if $T_L < T_R$
              then replace path field of RREQ packet with $T_L$
              updates its Id to path field of RREQ
          else
              forward the RREQ packet to next hop in the route
  if node =destination node
        wait w time slot to receive all RREQ
        for all RREQ received
        compare all the RREQ to find the minimum $T_L$
        append its address to the selected RREQ path field
        pop the nodes in the path field of selected RREQ
        change the mobility of the destination node to RREQ mobility value
  generate route replay through that path
        end if
   end if
  end if
end while

/*--------Reverse Path--------------*/
while node! = source
      pop node id's from path field of RREP
      update its mobility value to the value in RREP
      send RREP to the popped node Id
```



Algorithm-4 Improved Route Discovery Algorithm (IRDA).

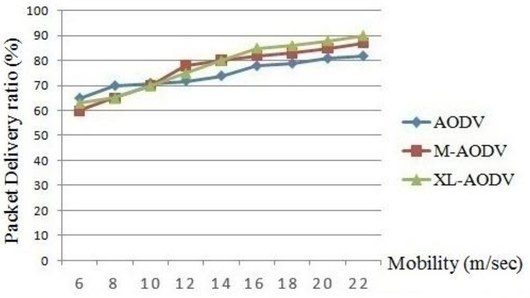
```
Let $H_{diff\_th}$ = 4 (Maximum difference in Hop Count)
Let $E_{th}$ = 20 jules (threshold energy)
Let $R_{act}$ = Active Route
Let $R_{alt}$ = Alternate Route
Let $T_R$ = Route Lifetime
if $R_{act}$.energy = $R_{alt}$.energy then
  if $R_{act}$.hopCount > $R_{alt}$.hopCount + $H_{diff\_th}$ then
    if $R_{act}.T_R \le R_{alt}.T_R$ then
      ShiftToRoute($R_{alt}$)
    end if
  end if
else if $R_{act}$.energy < $R_{alt}$.energy then
  if $R_{act}$.hopCount + $H_{diff\_th} \ge R_{alt}$.hopCount then
    if $R_{act}.T_R \le R_{alt}.T_R$ then
      ShiftToRoute($R_{alt}$)
    end if
  end if
else if $R_{act}$.energy > $R_{alt}$.energy and $R_{act}$.energy $\le R_{alt}$.energy + $E_{th}$ then
  if $R_{act}.T_R \le R_{alt}.T_R$ and $R_{act}$.hopCount > $R_{alt}$.hopCount + $H_{diff\_th}$ then
    ShiftToRoute($R_{alt}$)
  end if
end if
```

IV. PERFORMANCE EVALUATION

This section focuses on the implementation of an improved routing protocol, named cross-layer AODV (XL-AODV) in NS-2. It is a multipath routing protocol with remaining energy estimation and link availability detection mechanisms. It exploits hop count, remaining energy of nodes and link availability time information to select the optimal route. A comprehensive simulation study is carried out in 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 link quality prediction and improved route discovery) considers RSS, residual energy, link quality and the 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 1200s for three rounds at varying values.

In the simulation scenario, the impact of the speed of nodes on the performance of AODV, M-AODV and XL-AODV protocols is investigated. The number of nodes is selected as 50. The transmission range of each node varies between 20m and 50m, and it is assumed that there is a symmetric link between any two nodes if their geometric distance is smaller than the transmission range. Then, the start-up speed of the devices is changed from 4m/s to 25m/s. The obtained result against various mobility conditions is presented in the following paragraphs.

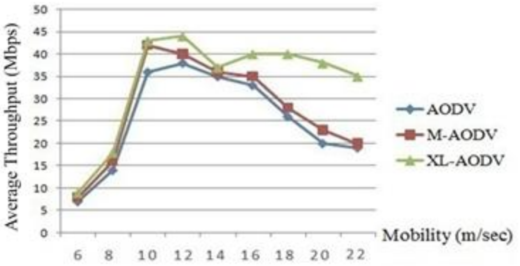
The packet delivery ratio of proposed XL-AODV is more compared to M-AODV and AODV as shown in Graph.1. As the mobility of the nodes increases, the possibility of link breakage increases for all protocols. Therefore, the packet drop rate also increases gradually. Nevertheless, by taking residual energy and link lifetime into account, XL-AODV has the maximum packet delivery ratio as compared to AODV. In XL-AODV, only a lesser amount of packets are 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 cache built into these protocols. Further, it is observed that the performance of XL-AODV is consistently uniform.



Graph1: Comparison of XL-AODV and other non-optimized protocols in terms of PDR for different mobility pattern

It can be seen from Graph.1 that XL-AODV clearly outdoes the 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, it is 79.35%. The enhancement realized by the XL-AODV protocol, compared to AODV is about 15.42% and compared to M-AODV is 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. The numerical results are obtained for the average throughput characteristic of routing protocols against various mobility conditions of the nodes.

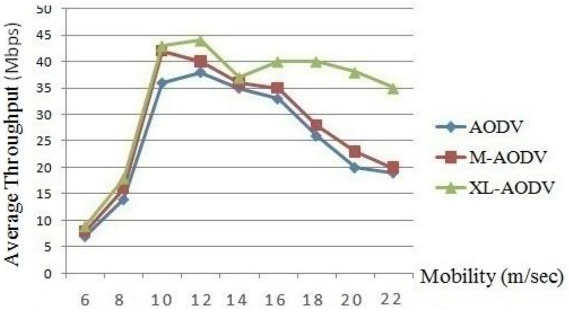
In the case of high mobility, M-AODV and XL-AODV improve the overall throughput of the network. This is because of the number of link failures in M-AODV and XL-AODV is decreased as compared to basic AODV. In AODV, the number of hops in the path fluctuates between low and high values, due to frequent link failures which make AODV to perform a new route discovery process. The average throughput of AODV is 24.5 packets/s and M-AODV is 26.6 packets/s whereas, for XL-AODV, it is 33.6 packets/s. Indeed, the improvement is about 37.14% higher than basic AODV and 26.3% higher than M-AODV. The behaviours of protocols studied are shown in Graph 2.



Graph 2:Comparison of XL-AODV and other non-optimized protocols in terms of Average Throughput for different mobility pattern

The delay of communication increases with node speed for all routing protocols as given in Graph 3. In the 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. The numerical results are obtained for the average throughput characteristic of routing protocols against various mobility conditions of the nodes.

Graph.3 illustrates the simulation results gained for the 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, the performance of AODV and M-AODV is worse as mobility leads to route errors and to the reestablishment 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, it is 0.56 sec which is 18.16% lesser than basic AODV and 5.42% lesser than M-AODV.



Graph 3: Comparison of XL-AODV and other non-optimized protocols in terms of End-to-end Delay for different mobility pattern

V. CONCLUSION

In this paper, an illustrative review of existing research on cross-layer designs is presented. The wide range of different intelligent cross-layer proposals reveals the importance of the cross-layer approach. As innovative wireless techniques are implemented, to boost the performance of the protocol stacks, cross-layer designs would be mandatory. On the other hand, there are also some open research issues restraining the growth of XLD in MANETs.In this paper, we proposed an optimized cross-layer design approach to provide systematic assimilation between the PHY, MAC and NET layer to share their locally available information efficiently. OXLD provides a combined solution for link availability prediction and optimal route discovery. This will result in a substantial performance improvement in terms of QoS constraints including average throughput, PDR and packet latency.

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