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Context-aware Routing to Assist Routing Decisions for Quality Improvement in Multi-Hop Ad hoc Networks

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ABSTRACT

The context information is an intriguing aspect of decision making. The context-awareness can be useful in the ad hoc networks in which nodes are mobile, and the conditions are dynamic. In ad hoc networks, routing protocols are intended to discover the route over multi-hop wireless links under varying conditions. The context-awareness can assist the routing protocols in determining the appropriate path. This paper investigates into choosing the appropriate route by applying the context information and presents the approach to improve the decision making and the quality of the route. We consider nodes, connecting links, and different layers as the context. The paper introduces the scalability and flexibility in the set of parameters that govern the eminence of the node inter-connection that, in turn, influences the overall quality of the route. We propose the context-aware dynamic routing protocol (CADR) and present the approach, algorithm, and analysis. We simulate the protocol by taking the flexible combination of the context attributes and the values, also compares the performance with AODV. The simulation results show that the protocol chooses the appropriate route as per the considered attributes and weight, and provide the enhanced performance.

Keywords: Ad hoc network; Context-aware; MANET; Quality; Routing protocol

1. INTRODUCTION

Mobile ad hoc networks (MANETs) comprehend the potential of providing services in unpredictable and emergency operational conditions. The eminence of quick deployment, less infrastructure cost, and the possibility of portable, on-the-move devices are fascinating. In spite of the challenges of vulnerable wireless links and unpredictable mobility, mobile ad hoc networks provide the multi-hop connectivity[1]. The dynamic connectivity in mobile ad hoc networks is achieved through effective routing strategies[4]. Routing protocols make it possible to appropriately forward the packets towards the intended destination and update their forwarding information in accordance with the network dynamism. The deployment situation, network constraints, and the application requirements significantly affect the approach to adopt the appropriate routing mechanism to meet the routing challenges. Primarily, there are two approaches to routing[10]. The first approach of proactive routing is to derive the routing information in advance and to update it periodically. The second method is to invoke the route finding process whenever there is a requirement. In this paper, we proceed with the reactive routing approach. One of the prevailing protocols in the reactive category is the ad hoc on-demand distance vector routing protocol that encompasses its elegant technique of destination sequence number to handle the count-to-infinity problem[3,19]. The protocol applies hop count as a metric to select the route to the destination[3]. The choice of the route with minimal hops may not always be appropriate for quality provision[15]. The quality of the route that, in turn, governs the service assurance depends on the capability and the quality of the underlying wireless link, which is influenced by factors like data rate, transmit power, link stability, etc., at the physical layer. Many proposals consider such parameters in deciding the route[16]. The proposal by Rath[5], *et al.* used an interaction-based cross-layer mechanism to improve the routing by considering the power and delay metric. Li[6], *et al.* proposed an algorithm that can handle multiple cross-layer parameters and govern reliable opportunistic routing. A proposal[9] was presented on dynamic packet guidance routing. The authors[2,11,13] suggest that the context information can be a useful asset in the ad hoc network. If the context information is exploited by the nodes, it may assist in device a good decision in the routing process. In a proposal by Abowd[7], *et al.*, context and context-awareness have been discussed. Musolesi[2], *et al.* applied context-awareness in delay tolerant mobile networks. Wenning[12], *et al.* in their proposal, suggested a framework for context-aware routing. Gellersen[11], *et al.* proposed the use of the multi-sensor context information in mobile devices. Musolesi[13], *et al.* suggested the use of context information for the intermittently connected network. In this paper, we contribute by proposing context-awareness in mobile ad hoc networks with the novelty of scalability and flexibility in choosing the context attributes based on the availability and

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requirement. We extract cross-layer information and consider flexible weight assignments to the attributes for their controlled effect in route selection. In this paper, we propose a context-aware dynamic routing protocol that considers attributes of the node during route selection and assigns appropriate weight to these attributes to calculate the routing metric for the path discovery. Paper simulates and evaluates the performance of the protocol.

2. PROPOSED CONSIDERATIONS AND CONTEXT

In this section, we present the key considerations and the context of the proposal. The context-awareness makes use of the context to provide useful information. The context-aware techniques extract information from the context and react based on the retrieved information[7]. The context information can be defined using a set of attributes $\{A_1, A_2, ...A_k\}$. Each attribute covers the set of its possible values[2], i.e., $A_x = \{x_1, x_2....x_m\}$. The performance of the network is influenced by various attributes of the network. The additive effect of the attribute can be given as $\sum_{i=1}^{k} A_i(x_i)$. To vary the impact of the attributes, weight assignment is used and is given as $\sum_{i=1}^{k} w_i A_i(x_i)$.

2.1 Base Protocol

The baseline protocol for our proposal is the context-aware adaptive routing (CAR), which utilises Kalman Filter prediction for routing of the messages, and is tailored for the delay-tolerant networks[2]. CAR assumes a proactive destination sequenced distance vector (DSDV) protocol for the synchronous deliveries, and when there are partitions, it utilises the store and forward mechanism for asynchronous transfers. In our proposal, we utilise the flexible attributes based on the current estimate of the context information rather than the prediction. We apply the concept in the reactive routing strategy in which the current estimate is more relevant for routing decisions. We take the source-code of ad hoc on-demand distance vector routing (AODV) as a baseline and tailor it for implementing our concept of the context-information in reactive routing. AODV makes use of the hop count to determine the route to the destination, and the discovered path is expected to be a minimum hop path. Although, there can be many situations when a path with quality of service is desired. As in the case of prevailing need for high data rate service, a route supporting the desired data rate should be followed while nodes with a low data rate to be avoided. Another prospect in the wireless scenario is the link quality[22] and the range, which is affected by the transmitted power of the node[24]. So it may be advantageous to adopt the path with suitable transmit power capabilities. In a similar way, there can be multiple context attributes and information which can assist the routing protocol in making the appropriate routing decisions. So we incorporate the flexibility and scalability in the attribute selection, and also utilise the cross-layer information.

2.2 Protocol Considerations

In the proposal, the context information is applied to device the routing decision dynamically. The choice of the parameters is scalable, and the suggested metric is flexible enough to consider the weight of an individual parameter. To incorporate the attributes of the lower layers, quality of the connecting links, and the information available at the routing layer[28], we adopt the routing metric calculation mechanism based on multiple inputs. The proposed context-aware dynamic routing protocol (CADR) considers the lower layer context information and routing layer information as the node context information (*NCI*). The protocol assigns a suitable weight to the attributes of the context information for the route metric calculation and utilises the calculated value as the weighted cost information (w_c) in route selection. The protocol provides the scalability in the number of attributes by utilising the availability index and auto-adjusts the index as per the available attributes. The protocol also maintains the route context information (*RCI*) based on the link quality for better route selection.

2.3 Node Context

The proposed protocol is flexible in the choice of parameters. We start the analysis of CADR by taking data rate, transmit power, and the battery capacity as the attributes of the node context information (*NCI*). The high data rate helps to meet the service quality, and transmit power relates to the link quality and the transmission range. The protocol considers these attributes in route selection with the flexibility to extend the parameter list. The protocol also incorporates hop count information available at the network layer in route metric calculation.

2.3.1 Transmit Power and Battery Capacity

For the information exchange, transmissions by the sender should be correctly received and decoded by the receiver. In wireless transmission, the reception of the signal depends on multiple factors[29] like distance, interference, background noise, collision, transmitted power, and the demises of power density, etc. There are a few parameters that can be maneuvered to ensure that the packet reception is unspoiled. We take the transmit power as one of the factors to simulate its effect on the quality of reception, as it directly influences the power received by the receiver[25]. If P_t is the transmitted power, power density[14] p at a distance r from an isotropic source is given by $p = P_t/4\pi r^2$. Let G_t is the gain of transmit antenna, the power received P_r by the receive antenna with A_e effective area can be given as $P_r = P_t G_t A_e / 4\pi r^2$. If receive antenna gain $G_r = 4\pi A_e / \lambda^2$, then received power is $P_r = P_t G_t G_r (\lambda / 4\pi r)^2$. For the given frequency and antenna gain, $P_r \propto P_t / r^2$ and $r \propto \sqrt{P_t}$. Hence, the communication range can be extended by increasing the transmit power within the permitted limit. If the communication range of nodes is high, there are chances to reach the signal at distant nodes in less number of hops. Even if the numbers of hops are equal, the path with better signal strength is likely to be more stable with a higher probability of correct packet decoding[20]. The weaker signal may result in network partitioning and incur a higher delay due to larger hop-counts[21]. Let's assume that nodes in the network have different transmit power capabilities. The transmit-power metric C_{pt} for the cost of the interface can be given by Eqn (1), where,

P_m is the maximum allowed transmit power, P_a is the actual transmitted power of the node, and the factor wt controls the influence of transmit power.

$$C_{pt} = \beta P_m / (P_a)^{wt} \tag{1}$$

One of the constraints in the ad hoc environment is the battery capacity of the participating nodes. Transmit power can impact the battery life, and the nodes transmitting higher power are expected to consume more energy[26, 27]. If the residual battery energy is below the threshold, it is not advisable to exhaust such nodes[21]. In order to improve the network lifetime while selecting the route, these nodes should be avoided. The metric value considering the battery constraints can be represented in terms of residual energy E_r, the initial energy E_i, and the factor we to control the impact of residual battery energy. The link cost can be given by Eqn (2)

$$C_{pe} = \mu E_i / (E_r)^{we} \tag{2}$$

Considering both transmit-power and battery-energy, the cost metric of the link is given by Eqn 3, where w_p and w_b represent the impact of power and battery respectively on the cost factor.

$$C_p = w_p \beta P_m \big/ P_a^{wt} + w_b \mu E_i / (E_r)^{we} \tag{3}$$

2.3.2 Data Rate and Bandwidth

Bandwidth requirement is dictated by the data rate, and it depends on the modulation and the coding schemes. If N_b bits are needed to specify the M possible symbols representing the order of the modulation, the number of bits per symbol can be given as $N_b = \log_2(M)$. The limit for maximum channel capacity (C) for the noiseless channel of bandwidth (B) is given as $2B\log_2(M)$. If the channel is noisy and the signal to noise ratio is S/N, then as per Shannon limit, the channel capacity $C = B\log_2(1 + S/N)$. If we assume a specific modulation and coding scheme, then the supported data rate (D) depends on the required bandwidth, i.e., $D \propto B$. To support high data rate traffic, all the connected links should have minimal carrying capability. If the network contains the nodes of different data rates, then to have the higher capacity path, it may be advantageous to select the nodes with higher data rate capability and, wherever possible, avoid low data rate nodes. If reference bandwidth represents the maximum supported data rate and link data rate signifies the available data rate, then the link metric for the cost of the interface favoring the high data rate path can be given by Eqn (4).

$$C_b = \begin{Bmatrix} B/(D - D_u), & D_u < D \\ \infty, & D_u \geq D \end{Bmatrix} \tag{4}$$

where B is the reference bandwidth, D represents the supported data rate, D_u is the existing flow, and C_b represents the link cost metric. $C_b = B/D$, if there is no existing data flow on the link.

2.4 Route Context

Route context information (*RCI*) has been taken as an indication of the quality of the route. The protocol takes link quality index (*LQI*) as the attribute of RCI and also considers the effect of hop count on RCI. The higher value of the *RCI* reflects a better quality path. CADR defines it as the minima of the quality of connected links in the selected route. If there are k connected links in a route, the *RCI* can be given by Eqn (5). Where, $RCI(R)$ is the quality index of the route R between two distant nodes of the network and $LQI(\eta)$ is the quality index[17] of the link η over the route *R*.

$$RCI(R) = min\{LQI_1(\eta), LQI_2(\eta), \ ..., LQI_k(\eta)\} \tag{5}$$

2.4.1 Link Quality Index

CADR proposes *LQI* to be governed by the stability and bit error rate attributes of the link. Bit error rate (*BER*) represents the ratio of the erroneous bits to the total bits received over a period of time and gives an indication of the quality of the link. The link stability reflects the steadiness of the link over the period of time and indicates the link quality and sensitivity to the topology change. This parameter is governed by various factors[8] like distance, mobility, etc. *LQI* governs the success probability of data transfer over the link and is derived from the lower layer information, as given in Eqn (6). Where, B_i is i^{th} sample of *BER* in last n observations and $L_s(t)$ is the link stability parameter observed during the period t. The parameters wb and w_l are the weight factors for BER and link stability, respectively. The protocol assigns the binary feedback factors f_e and f_s for bit error and link stability, respectively, based on the availability of these parameters by the physical layer.

$$LCI_i(\eta) = f_e\left(\sum_{i=1}^{n} B_i \bigg/ n\right)^{-wb} + f_s w_l L_s(t), \ t_0 < t < t_0 + T \tag{6}$$

2.4.2 Hop Count Consideration

In multi-hop wireless networks, a higher number of hops can give an upsurge to the instability of the route. With the increase in the number of links, network stability decreases, and the chances of packet loss increases[23]. Let P_k is the probability of the existence of the k-hop route in a multi-hop environment. If the distribution of nodes in a given area follows the Poisson distribution $P(N = n) = \lambda^n e^{-\lambda} \big/ n!$ where λ is given as $\mu \times A$ and μ represents nodes per unit area. If N_A denotes nodes in area A, then the value[23] of P_k can be given by Eqn (7). Based on the value of P_k maximum hop count can be deduced for the desired connectivity threshold.

$$P_k = \sum_{j=1}^{\infty} \frac{\lambda^j}{j!} e^{-\lambda} P(k \mid N_A = j) \tag{7}$$

In the multi-hop connectivity, $(d_{ij} < r_{com})$ is desired for each hop, where d_{ij} the distance between node *i* and node *j* and r_{com} is the communication range of the node. The probability of direct connection can be given as $P_c = P(d_{ij} < r_{com|} \mid k = 1)$. If node density in the region is *n*, then connectivity occurrence probability is $P_{co} = 1 - (1 - P_c)^n$. The route connectivity probability[18] P_r between source n_s and destination node n_d connected through the k-hop path can be given by Eqn (8).

$$P_r = (1 - (1 - P_c)^n)^{k-1} \tag{8}$$

From Eqn 8, it can be deduced that if the chosen path has less number of hop-counts, then the path is expected to be more reliable. If hop-count is the cost metric and there is no other quality constraint, the path selection is preferred based on the minimum hop path, and the cost of the path consisting of *h* number of hops can be given by Eqn (9), where η represents the measurement of a single hop.

$$C_h = \sum_{i=1}^{h} (\eta) \tag{9}$$

3. CONTEXT-AWARE DYNAMIC ROUTING MECHANISM

The approach and the algorithm of the proposed protocol have been outlined in this section. The protocol suggests scalability in the number of attributes and flexibility in choosing the opted attributes.

3.1 Metric Selection

As an example scenario, we take the combination of the hop count, bandwidth, and transmit power for the routing metric, while protocol provides the flexibility to select other parameters also. In this scenario, the availability index is three, and the protocol automatically discards unavailable attributes from the calculation. Each parameter is given the weight to calculate the metric for route selection. Let, the cost of the hop count is C_h, and the cost of bandwidth (data rate) and transmitted power are C_b and C_p, respectively. Let, α, δ, γ are the weight of C_h, C_b, and C_p, respectively. The routing metric as weighted cost information (W_c) is given by Eqn (10).

$$W_c = \alpha C_h + \delta C_b + \gamma C_p, \ \forall\ 0 \leq (\alpha, \delta, \gamma) \leq 1,\ \alpha + \delta + \gamma = 1 \tag{10}$$

Based on the choice of metric and the value of α, δ, and γ, there can be different combinations of weighted cost as per the service requirements, as illustrated below.

(i) *Hop count:* Number of hops to choose the shorter path, $W_c = C_h,\ \mathit{if}\ (\alpha = 1, \delta = 0, \gamma = 0)$

(ii) *Bandwidth:* Bandwidth to choose the high data rate path, $W_c = C_b,\ \mathit{if}\ (\alpha = 0, \delta = 1, \gamma = 0)$

(iii) *Transmit power:* Transmit power to select the good quality path, $W_c = C_p,\ \mathit{if}\ (\alpha = 0, \delta = 0, \gamma = 1)$

(iv) *Bandwidth and transmit power:* A combination of bandwidth and transmit power for high data rate quality path, $W_c = \delta C_b + \gamma C_p,\ \mathit{if}\ (\alpha = 0, \delta \neq 0, \gamma \neq 0)$

(v) *Hop count, bandwidth, and transmit power:* Combination of the parameters to select the high bandwidth and good quality route with the optimal number of hops. $W_c = \alpha C_h + \delta C_b + \gamma C_p,\ \mathit{if}\ (\alpha \neq 0, \delta \neq 0, \gamma \neq 0)$

3.2 Route Selection

CADR protocol is reactive in nature, and for the on-demand route discovery utilises the concept of the broadcast of route request and unicast of route reply back to the source. In the proposed approach, the extended route request (R_{re}) contains the information about the weighted cost (w_c) and route context information (*RCI*). The algorithm makes use of the destination sequence number and the weighted cost information instead of the sequence number and the hop count to decide the forward or discard action on the packet. If the incoming sequence number (S_n) is lower than existing (S_e), the packet is discarded to avoid stale information. If the incoming sequence number is the same as the stored information, but the weighted cost is lower than the previous cost, then this route request is forwarded. To reflect the impact of the weighted cost on the selected route, the cost of the node is added to the cumulative cost. If the current cumulative cost at the destination is lower than the existing cost, then it is considered the better route, and a route reply with the weighted cost information is sent back to the source. While forwarding towards the source, the cost of the nodes in route reply is also added at every hop. This gives a low-cost route based on the selected weight of various parameters in the weighted cost. If the source gets more than one route reply (R), it compares the weighted cost information, and the route with lower cost is selected i.e. $R_s = \{r \in R \mid w_c^r < w_c^q, \forall q \in R\}$. If the weighted cost of the two routes is the same, then the route with better route context information is preferred, as illustrated below.

$\mathit{if}\ (S_n < S_e)\ \{\mathit{discard}\ R_{re}\}$

$\mathit{if}\ (S_n > S_e)\ \{\mathit{process}\ R_{re}\}$

$\mathit{if}\ (S_n = S_e)\ \mathit{and}\ (w_{c\_n} < w_{c\_e})\ \{\mathit{process}\ R_{re}\}$

$\mathit{if}\ (S_n = S_e)\ \mathit{and}\ (w_{c\_n} = w_{c\_e})\ \mathit{and}\ (RQI_n > RQI_e)\ \{\mathit{process}\ R_{re}\}$

3.3 Packet Details

The protocol makes use of the extended route request and extended route reply to carry the cumulative weighted cost and route context information during the route discovery phase. In the extended route request packet, as shown in Fig. 1, the source address field signifies the IP address of the originating node. The destination address represents the IP address of the destination. The source sequence number is used to maintain the freshness of the reverse route towards the originator of the route request. The destination sequence number contains the latest sequence number available at the originator for any route towards the destination and indicates the freshness of the route to the destination. Route request Id uniquely identifies route-request for a particular source. The packet also contains the type, flags, and hop count fields for compatibility with AODV. The additional fields in the packet are cumulative weighted cost information and route context information (*RCI*). The cumulative weighted cost is used to carry the value of the route selection metric, which is recalculated at every node based on the routing information and the feedback of the lower layers. The RCI indicates the quality of the route based on the lower layer context information. The extended route reply also contains the fields for cumulative weighted cost and RCI.

3.4 CADR Algorithm

The algorithm of the CADR protocol selects the appropriate route in a multi-hop ad hoc environment. It considers the context information in the route calculation. Algorithm-1 outlines the foundation methodology of the protocol, and the notations used in the algorithm are given in Table 1.

<table>
<tr><td>*Type (8 bits)*</td><td>*Flags (5 bits)*</td><td>*FE (11 bits)*</td><td>*Hop count (8 bits)*</td></tr>
<tr><td colspan="4">*RREQ Id (4 bytes)*</td></tr>
<tr><td colspan="2">*Destination address (4 bytes)*</td><td colspan="2">*Destination sequence 4 bytes)*</td></tr>
<tr><td colspan="2">*Source address (4 bytes)*</td><td colspan="2">*Source sequence (4 bytes)*</td></tr>
<tr><td colspan="4">*Weighted cost information (4 bytes)*</td></tr>
<tr><td colspan="4">*Route context information (4 bytes)*</td></tr>
</table>

Figure 1. Extended route request.

Table 1. Notations used in the algorithm

Notation	Definition
N_i	Node i
S	Source node
D	Destination node
P_i	Control packet info
R_i	Route info
RT	Routing table
R_{ereq}	Extended route request
R_{erep}	Extended route reply
R_{err}	Route error
R_{ci}	Route context information
H_c	Hop count
C_c	Cumulative cost information
W_c	Weighted cost information

$\textbf{\textit{Algorithm}}1: \textit{CADR Protocol Route Discovery}$

$\textit{Find Route}(S, D)$

$\textbf{\textit{in}}: \textit{control packets } R_{ereq}; R_{erep}; R_{err}$

$\textbf{\textit{out}}: \textit{unicast route to } D$

$S \textit{ create } R_{ereq}$

$W_c \leftarrow \sum_{i=1}^{index} w_i C_i;\ C_c \leftarrow W_c;\ H_c \leftarrow 0$

$\textit{broadcast } R_{ereq}$

$I \leftarrow \{\textit{Set of nodes receiving control}\}$

$\textbf{\textit{for all }} i \in I \textbf{\textit{ do}}$

$\quad \textbf{\textit{if}}\ (P_i = R_{ereq})\ \textbf{\textit{then}}$

$\quad\quad \textbf{\textit{if}}\ (R_{ereq} seq = old)\ \textbf{\textit{then}}$

$\quad\quad\quad \textit{discard request}$

$\quad\quad \textbf{\textit{end if}}$

$\quad\quad \textbf{\textit{if}}\ (N_i \neq D)\ \textbf{\textit{then}}$

$\quad\quad\quad \textbf{\textit{if}}\ \textit{same sequence}\ \textbf{\textit{then}}$

$\quad\quad\quad\quad \textbf{\textit{if}}\ (C_c > \textit{previous } C_c)\ \textbf{\textit{then}}$

$\quad\quad\quad\quad\quad \textit{drop request};\ \textbf{\textit{end if}}$

$\quad\quad\quad \textbf{\textit{end if}}$

$\quad\quad\quad C_c \leftarrow C_c + W_c;\ \textit{update } R_{ci}$

$\quad\quad\quad H_c \leftarrow H_c + 1;\ \textit{setup reverse path}$

$\quad\quad\quad \textit{rebroadcast } R_{ereq}$

$\quad\quad \textbf{\textit{else if}}\ (N_i = D)\ \textbf{\textit{then}}$

$\quad\quad\quad \textbf{\textit{if}}\ (C_c < \textit{previous } C_c)\ \textbf{\textit{then}}$

$\quad\quad\quad\quad H_c \leftarrow 0 \textit{ in } R_{erep}$

$\quad\quad\quad\quad \textit{send } R_{erep} \textit{ to } S;\ \textbf{\textit{end if}}$

$\quad\quad \textbf{\textit{end if}}$

$\quad \textbf{\textit{else if}}\ (P_i = R_{err})\ \textbf{\textit{then}}$

$\quad\quad \textit{mark route invalid}$

$\quad \textbf{\textit{else if}}\ (P_i = R_{erep})\ \textbf{\textit{then}}$

$\quad\quad \textbf{\textit{if}}\ (N \neq S)\ \textbf{\textit{then}}$

$\quad\quad\quad C_c \leftarrow C_c + W_c;\ \textit{update } R_{ci}$

$\quad\quad\quad H_c \leftarrow H_c + 1;\ \textit{setup forward path}$

$\quad\quad\quad \textit{forward } R_{erep} \textit{ towards } S$

$\quad\quad \textbf{\textit{else if}}\ (N = S)$

$\quad\quad\quad \textbf{\textit{if}}\ (C_c < \textit{previous } C_c)\ \textbf{\textit{then}}$

$\quad\quad\quad\quad \textit{update RT of } S$

$\quad\quad\quad \textbf{\textit{else if}}\ (C_c = \textit{previous } C_c \textit{ and } R_{ci} > R_{ci\_previous})\ \textbf{\textit{then}}$

$\quad\quad\quad\quad \textit{update RT of } S; \textbf{\textit{end if}}$

$\quad\quad\quad \textbf{\textit{end if}}$

$\quad \textbf{\textit{end if}}$

$\textbf{\textit{end for}}$

$\textit{send to next hop towards } D$

$\textbf{\textit{return}}\ R_i$

4. SIMULATION ANALYSIS

CADR protocol has been envisioned with the routing metric dictated by the combination of node context information and the route context information. In the case of multiple attributes, the assigned weight influences the impact of the parameter. This feature enriches the protocol to adjust its route selection progression as per the network conditions and user requirements. To analyse the performance, we simulate the proposed protocol by taking the data rate and transmit power as the attribute of the lower layer context information while the hop-count as an attribute at the routing layer. We have taken the different values of data rate in the range of 1 Mbps to 11 Mbps and have considered different topologies and number of nodes. We have simulated the protocol using the OPNET simulator considering the various combinations of attributes like single attribute, two attributes, and the combined effect of multiple attributes. The simulation parameters, protocol parameters, and traffic parameters are mentioned in Tables 2, 3, and 4, respectively.

Table 2. Simulation parameters

Parameter	Value
Simulation time	300 sec
Data rate	11 Mbps, 5.5 Mbps, 2 Mbps, 1 Mbps
Transmit power	5 *mW*, 2 *mW*, 1 *mW*
Packet reception threshold	-95 *dBm*

Table 3. CADR parameters

Parameter	Value
RREQ rate limit	10 packets/sec
RREQ retries	5
Active route time out	3 sec
Node context information	Data rate, transmit power
Node and route context information	Hop count, data rate, transmit power
Metric weight	0 to 1

Table 4. Traffic pattern

Simulation time (s) (T = 300 s)	Packet generation rate (packets/s)	Packet size (bytes)
(0, 10)	0	NA
(T/30, 65)	1	128
(T/20, T)	100	1250

To analyse the impact of the various route-metric on the protocol, we have taken the scenario $G = \{N, L\}$ in which $N = \{1, 2, 3......n\}$ nodes are participating, and the links are represented by $L = \{1, 2, 3.....m\}$ in the simulation area of 5×5 km, where N is a variable representing node density. All the nodes are equipped with the wireless interface and make use of CADR protocol. Participating nodes have IP capabilities, and the source node i generates the traffic to a destination j, such that $i \neq j$. In the simulation, at time $T = 10$ *sec,* the source starts IP traffic for the intended destination. At time $T = 15$ *sec,* the source node increases traffic generation at the rate of 100 packets per second with exponentially distributed packet inter-arrival time. The performance metrics for the analysis are traffic received and the end to end delay. The received data traffic has been measured by the total number of packet bits received per second by the destination node. The delay metric is measured as the end to end delay of IP packets between source and destination. We have arranged the analysis in multiple cases as outlined below in which different combinations of attributes and their values have been taken.

(i) Single flexible attribute: To analyse the effect of the flexible attribute, we take data rate and hop count as the flexible attributes of the routing metric. We select a single attribute in one cycle by enabling its weight while disabling other attributes in the same cycle. In this analysis, we compare the effect of each flexible attribute. We have taken the scenario in which there exist two paths between source and destination. The first path is shorter with hop count four, but nodes in the path have a limited data rate of 1 Mbps. While the second path is longer and contains six hops, and all the nodes along this path have a high data rate capability of 11 Mbps. We simulate the protocol by considering the data rate as the attribute of the context information and assign weight (1) to the data rate and (0) to the other attributes. We also simulate the protocol vice-versa in which weight (1) is assigned to hop count and (0) to the other attributes. We compare the performance of the CADR with the AODV protocol. The results are shown in Fig. 2, expressing the comparison of the hop count, delay, and the traffic received. The average value of delay without context information is 0.5208 seconds. While for CADR, the delay reduces to 0.4410 seconds, which shows an improvement of 0.0798 seconds. In the considered scenario, the statistics of average traffic received is 386.684 kbps and 192.536 kbps for CADR with context information and the AODV without context information, respectively.

The results illustrate that CADR selects the higher data rate path and performs better in comparison to the low data rate path of AODV. In this situation, despite the higher number of hops, the observed delay is less in the high data rate path than in the other path. There is also a considerable improvement in received traffic at the destination node for CADR.

(ii) Single attribute: To explore the impact of transmit-power as a single attribute, we assign the weight (1) to the transmit power and (0) to other parameters. We have taken the three situations in which nine nodes participate in the network. In the first situation, all nodes in the network have low power-

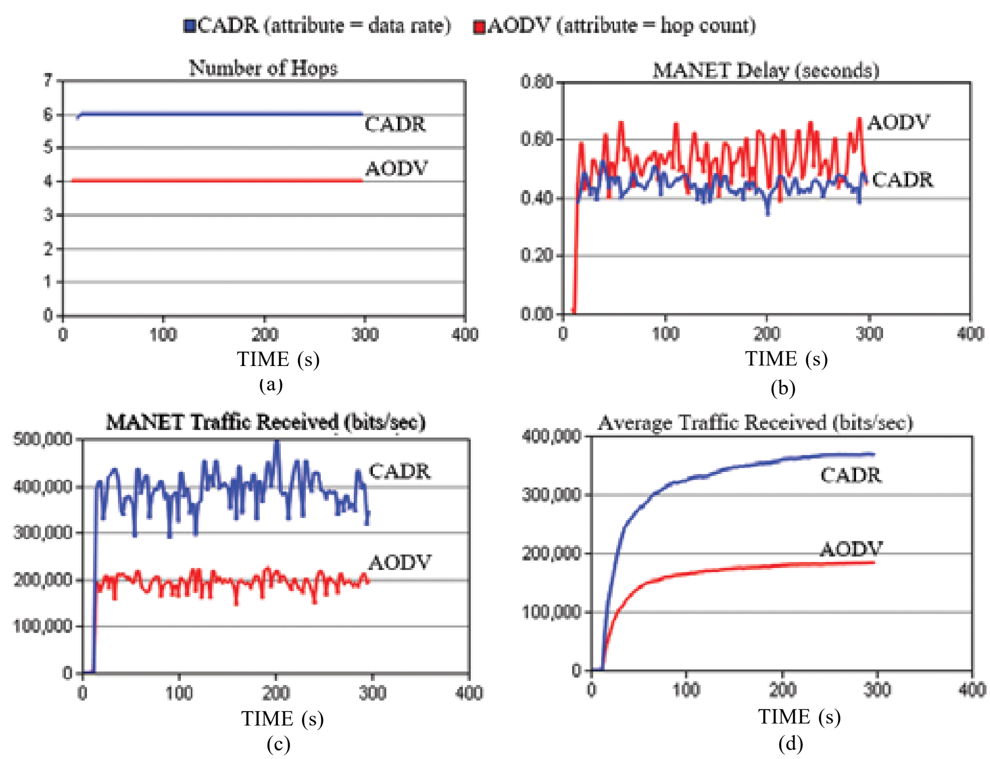

Figure 2. Performance with bandwidth and hops as routing metric (a) Hop count, (b) Delay, (c) Instantaneous traffic received, and (d) Average traffic received.

capability of the order of 1 *mW* (L). Nodes exhibit a limited communication range, and only one path of 5 hops exists from the source to destination. In the second situation, three of the participating nodes increase the transmit-power to 2 *mW* (M), which extends the range and results in a new path of 4 hops. In the third situation, transmit power is increased to 5 *mW* (H). This further extends the range and creates a 3 hop path. The comparative results reflecting the effect of transmit-power on the number of hops and received traffic are shown in Fig. 3. The result elucidates that when there is an increase in transmit power, the number of hops between source and destination decreases due to the increased transmission range of the wireless nodes. It is also observed that the drop in traffic is less for channels with higher transmit-power. Results show that when there is an upsurge in power from 1 *mW* to 2 *mW*, significant improvement is observed in received traffic. When power is further increased from 2 *mW* to 5 *mW*, the number of hops reduces by one. In this case, there is only a slight improvement in the received traffic because it is already approaching the transmitted traffic.

(iii) Dual flexible attributes: In this scenario, data rate and transmit power are taken as two attributes. We do flexible analysis by keeping one parameter high and the other low and vice-versa. There exist two possible routes of an equal number of hops between source and destination. One route is the power dominated while the other is the bandwidth dominated path.

In the power dominated path (C1), nodes have the transmit power of 5 *mW* and a data rate of 2 Mbps. While in bandwidth dominated path (C2), nodes have the data rate capability of 11 Mbps and can transmit 2 *mW* of power. In the CADR protocol, we first chose the bandwidth as the routing metric by assigning weight 1 to the data rate and 0 to transmit power. Under similar circumstances, we switch the metric to transmit power by assigning weight 1 to transmit power and zero to the data rate and analyse the impact. We found in results that the protocol chooses the appropriate path as dictated by the metric. Figure 4 displays the characteristics of delay and the received traffic by the destination node. The average delay value for C1 and C2 is 0.312334 seconds and 0.296477 seconds, respectively. The average rate of traffic received is 381.188 kbps and 678.476 kbps, for C1 and C2, respectively. The results indicate that if the power is well enough to cover the desired communication range, then it is advantageous to select the higher data rate path. Less delay and the improved received traffic is measured on the high data rate path.

(iv) Combination of multiple attributes: In this case, we analyse the behaviour and performance of CADR protocol using the weighted combination of hop count, data rate, and transmit power attributes in the routing metric by assigning 0.5 weight to the data rate and 0.25 to each transmit power and hop count. We observe the findings that when multiple routes are available.

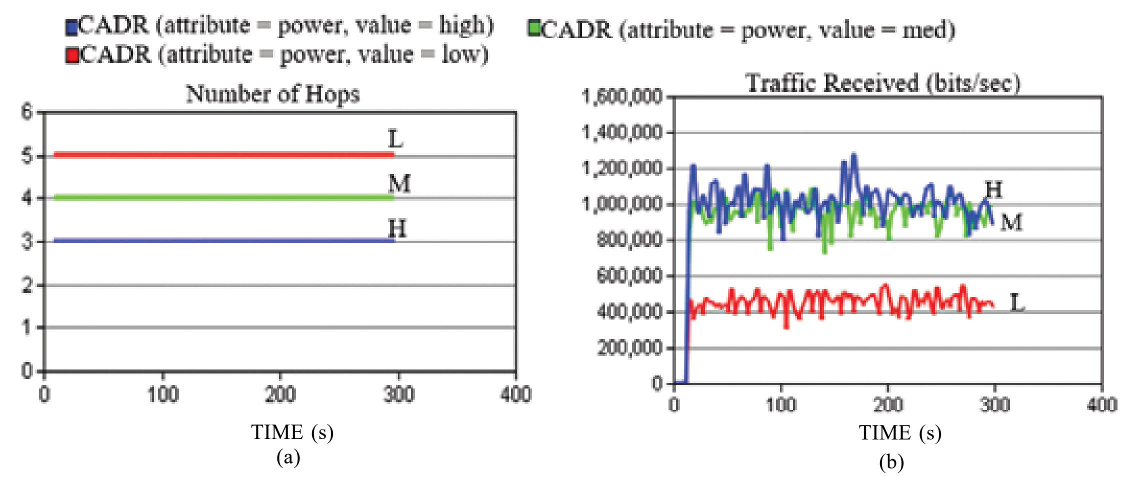

Figure 3. Performance with varying transmit power (a) Hop count and (b) Traffic received.

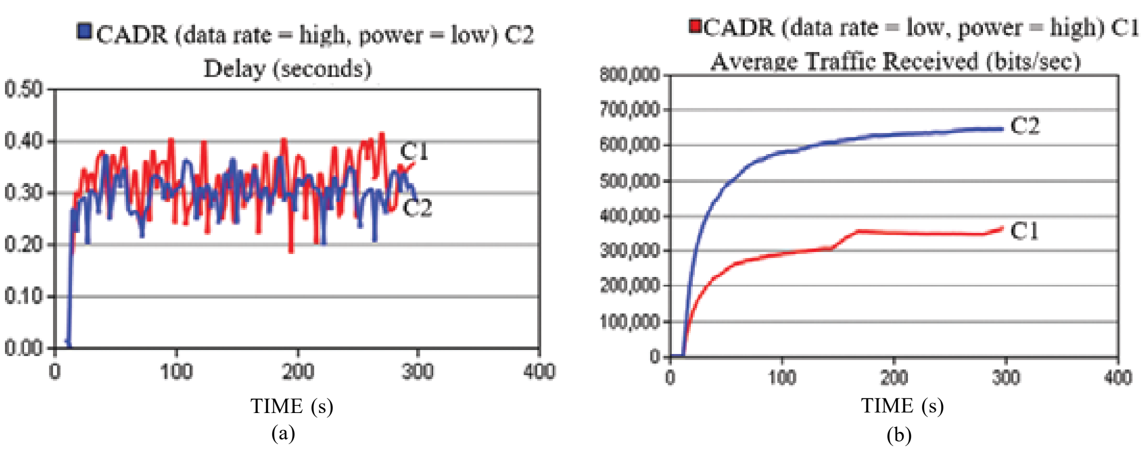

Figure 4. Statistics with varying data rate and power (a) Delay statistics and (b) Average traffic received.

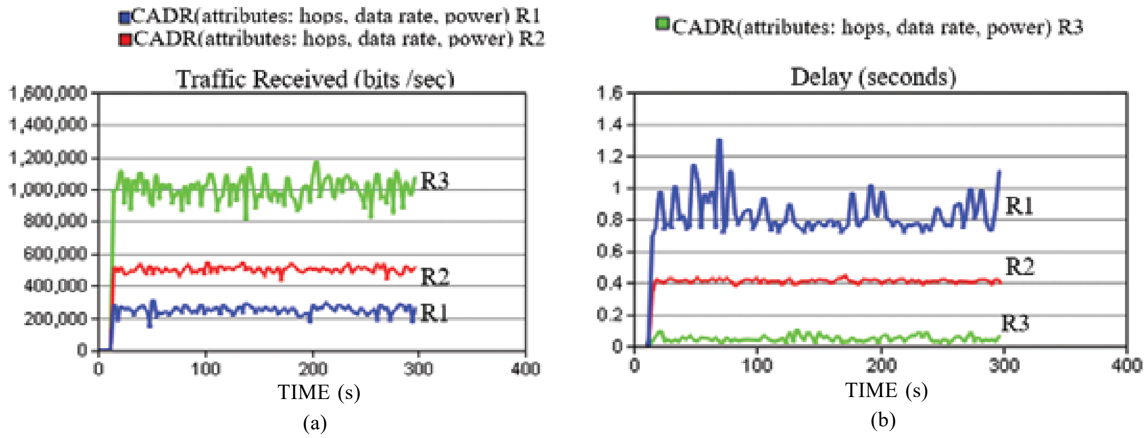

Figure 5. Protocol behaviour on multiple possible paths (a) Traffic received and (b) Delay statistics.

In this case, initially, nodes are in string topology with a transmit-capability of 2 *mW* and a data rate of 1 Mbps that formulates three hops (R1) from source to destination. In the second configuration, two additional nodes join the network having transmit-power of 5 *mW* and 2 Mbps data rate and create a new path (R2) from source to destination. In the third configuration, further two nodes enter the network having 5 *mW* transmit power and the data rate capability of 5.5 Mbps and create the third path (R3). We analyse the protocol and observe that the protocol chooses the most appropriate path, and hence improvement in performance is perceived. The comparative results of the observed delay and data received by the destination are shown in Fig. 5. The protocol calculates the cost and quality of the path by considering the appropriate weight of the parameters. The protocol selects the better quality path with less cost. An average received traffic of 242.916 kbps, 490.307 kbps, and 971.375 kbps is observed in the paths R1, R2, and R3, respectively.

5. CONCLUSION

In this paper, we proposed a context-aware dynamic routing protocol. The protocol is based on the context information and makes use of the node context and route context information for appropriate route selection. The proposed approach supports flexibility in choosing the context and in assigning the weight to the various attributes of the information. It is evident by the simulation results that the protocol selects the appropriate path and provides improved results. In the case of data rate as the attribute of context information, the delay-improvement of 15.32% is observed with respect to the protocol unaware of the context information. The proposed protocol chooses the better path, and in the considered scenario, the traffic received is 386.684 kbps, which is significantly high with respect to the 192.536 kbps without the context attributes. The study of dual attributes indicates the flexibility and the effect of attributes on the protocol performance. The results of the combination of multiple attributes show that as the context information and the choice of the path increase, the protocol selects a more appropriate route, as governed by the context attributes. The proposed protocol will be useful to assist the routing decision for the quality route in the mobile ad hoc networks.

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