Route Handoff in Mobile ad hoc Networks

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Abstract: *Mobile ad hoc networks are characterized by multi-hop wireless links, absence of any cellular infrastructure, and frequent host mobility. Design of efficient routing protocols is a challenging issue in such networks. Transmissions of packets are impaired by radio link fluctuations. Thus, in this paper an enhanced, channel adaptive routing protocol extensions to a multipath routing protocol known as Ad hoc On-Demand Multipath Distance Vector routing protocol, to accommodate channel fading is introduced. The resulting protocol is referred to as Channel Aware-Ad hoc On-Demand Multipath Distance Vector routing protocol. This routing protocol is quite suitable that uses the channel average nonfading duration as a routing metric to select stable links for path discovery. By exploiting channel state information, it applies a preemptive handoff strategy to maintain reliable and stable connections. Paths can be reused when they become available again, rather than simply regarding them as useless. We provide theoretical expressions for network performance measures, as well as the differences in performance between the two routing protocols mentioned above.*

Key words: routing protocols ad hoc networks, , on demand routing, channel state dependent, adaptive.

I. Introduction

Ad hoc network is a particular wireless mobile network, which is characterized by multi-hop routing and dynamic topology. Transmission is highly affected by path loss and signal/channel fading [1]. In order to reduce routing overheads, on-demand routing protocols build and maintain only needed routes. In on-demand protocols also known as reactive protocol, a route discovery process is initiated whenever a route is needed. High route discovery latency together with frequent route discovery attempts in dynamic networks can affect the performance adversely [2]. Multipath on-demand protocols try to alleviate these problems by computing multiple paths in a single route discovery attempt [3]. Multiple paths could be formed at both traffic sources as well as at intermediate nodes. New route discovery is needed only when all paths fail [4].

Thus *on-demand, multipath distance vector* protocol as an extension to a well-studied single path routing protocol known as Ad hoc On-demand Distance Vector (AODV) is utilized. Protocol named as Ad hoc On-demand Multipath Distance Vector (AOMDV) protocol. Primary design goal behind AOMDV is to provide efficient fault tolerance in the sense of faster and efficient recovery from route failures in dynamic networks [5]. The main drawbacks of AOMDV routing protocol is that it depends only on the no. of hops for choosing a path [6]. Stability of the path is ignored.

Our goal here is to develop a channel aware on-demand routing protocol as an extension to a well-studied multipath routing protocol known as Ad hoc On-demand Multipath Distance Vector (AOMDV).We refer to the new protocol as *Channel Aware- Ad hoc On-demand Multipath Distance Vector* (CA-AOMDV) protocol. Primary design goal behind CA-AOMDV is to provide efficient preemptive handoff when the predicted path incurs fading. With the knowledge of Channel State Information, the signal strength and path stability can be known [7]. This allows us to predict the fading in the signal. Thus the signal is handover to alternate path [8]. To achieve this goal, CA-AOMDV computes two parameters. They are life time and down time of a fading signal. By the same information the path can be reused rather than simply regarding them as failure or useless. This avoids unnecessary route discoveries, predicting path failure leading to handoff and then bringing paths back into play when they are again available. We use specific, timely, channel quality information for path availability.

In Section 2, we review protocol AOMDV. Channel prediction algorithm, phases and hand off of CA-AOMDV, routing protocol are discussed in Section 3. In Section 4, detailed theoretical analysis and results are presented and conclusions in Section 5.

II. Ad Hoc on-Demand Multipath Distance Vector Routing

2.1 Overview of AODV

AODV, on demand routing protocol, is based on hop-by-hop routing approach. It is the single path routing protocol [9]. The two phases in this protocol are Route Discovery and Route Maintenance. When a traffic source needs a route to a destination, it initiates a route discovery process. Route discovery typically involves a network-wide flood of route request (RREQ) packets targeting the destination and waiting for a route reply (RREP). Each route discovery is associated with high- overhead and latency. Route maintenance is done using route error (RERR) packets. When a link failure is detected, a RERR is sent back via separately maintained predecessor links to all sources using that failed link. Sequence numbers in AODV play a key role in ensuring loop freedom. Every node maintains a monotonically increasing sequence number for itself.

2.2 AOMDV

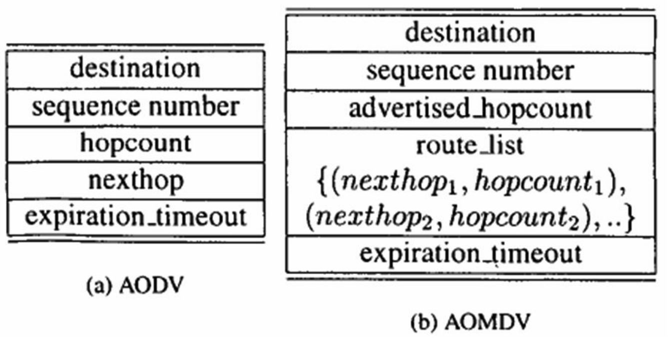
The main idea in AOMDV is to compute multiple paths during route discovery. It is designed primarily for highly dynamic ad hoc networks where link failures and route breaks occur frequently. When single path on-demand routing protocol such as AODV is used in such networks, a new route discovery is needed in response to every route break. This inefficiency can be avoided by having multiple redundant paths available. Now, a new route discovery is needed only when all paths to the destination break. A noteworthy feature of the AOMDV protocol is the use of routing information already available in the underlying AODV protocol as much as possible. Thus little additional overhead is required for the computation of multiple paths. The AOMDV protocol has two main components:

1. A route update rule to establish and maintain multiple loop-free paths at each node.
2. A distributed protocol to find link-disjoint paths.

AOMDV is to provide faster and efficient recovery from route failures in dynamic networks. To achieve this goal, AOMDV computes “multiple loop-free and link-disjoint paths.” The notion of an “advertised hop count” is used to maintain multiple loop-free paths with the same destination sequence number. In both protocols, on receiving RREQ initiates a node route table entry in preparation for receipt of a returning RREP. The difference in Routing table entries is shown in figure 1.

III. Channel-Aware Ad Hoc On-Demand Multipath Distance Vector Routing

The main drawback of AOMDV is that it depends on the number of hops in choosing a path. Path stability is completely ignored.



destination
sequence number
hopcount
nexthop
expiration_timeout

(a) AODV

destination
sequence number
advertised_hopcount
route_list $\{(nexthop_1, hopcount_1),$ $(nexthop_2, hopcount_2), ..\}$
expiration_timeout

(b) AOMDV

Fig. 1: Routing table entries for AODV and AOMDV.

Frequent link failures occur because selected paths tend to have a small number of long hops. This shows that nodes are already close to the maximum possible communication distance apart. Further, channel conditions are idealized with the path-loss/transmission range model, fading characteristics are ignored. In CA-AOMDV, the deficiency is addressed in two ways.

1. In the route discovery phase, average non fading duration, of each link as a measure of its stability is utilized.
2. In the route maintenance phase, instead of waiting for the active path to fail, preempt a failure by using channel prediction on path links, allowing a handover to one of the remaining selected paths. This results in saved packets and consequently smaller delays.

3.1 Channel Prediction Algorithm

CA-AOMDV utilizes Channel prediction Algorithm using Time Correlation for examining handoff between paths, when a fade is predicted on a link on the active path. For channel prediction linear minimum mean square error (LMMSE) algorithm is used.

Let M be the number of previously received values for predicting, at *n* discrete time interval with a discrete time step of ∆t. Let the signal strength be ψ. Then, $\hat{x}(n+\psi)$ is the LMMSE prediction for the received signal strength, *x(n+ψ)* at discrete time (*n+ψ)* , we have $\hat{x}(n+\psi)$ given by,

$$\sum_{i=1}^{M} w(i)x(n-i), \quad (1)$$

where *x(n-i)* is the incoming signal sample value at time *(n-i). w(i)* is the prediction weight for i^{th}
previous input signal sample value.
(1) Can be written as

$$\hat{x}(n+\psi) = \mathbf{R}_{\hat{x}x}^{T}\mathbf{R}_{xx}^{-1}\mathbf{x}, \quad (2)$$

where R^T_{xx} is the 1xM cross-correlation vector of *x*^ and *x,* $(.)^T$ denotes transpose, R_{xx} is the MxM autocorrelation matrix of *x*= [*x(n-1),x(n-2),..,x(n-M)*]^T , and x is the Mx1 vector of the M previous signal strength values. Where autocorrelation matrix R_{xx} is given by,

$$\mathbf{R}_{xx} = \begin{bmatrix} R_{xx}(1,1) & R_{xx}(1,2) & \cdots & R_{xx}(1,M) \\ R_{xx}(2,1) & R_{xx}(2,2) & \cdots & R_{xx}(2,M) \\ \vdots & \vdots & \cdots & \vdots \\ R_{xx}(M,1) & R_{xx}(M,2) & \cdots & R_{xx}(M,M) \end{bmatrix}, \quad (3)$$

Where R_{xx} (l, m) element is given by,

$$\begin{aligned} R_{xx}(\ell,m) &= E\{x(n-\ell)x^H(n-m)\} \\ &= \sigma_1^2 J_0(2\pi f_T(m-\ell))J_0(2\pi f_R(m-\ell)), \end{aligned} \quad (4)$$

Where $(.)^H$ denotes Hermitian transpose. *Jo* is the 0^{th} order Bessel function of first kind. The Bessel functions in the LMMSE algorithm are computationally intensive.

3.2 Parameter Calculation

Node to node channel model is used. The speed between two nodes rather than relative speeds of mobile nodes is calculated. Two parameters are calculated. They are average nonfading duration (life time) and average fading duration (down time).

Average Nonfading Duration (ANFD) is defined as average length of time that the signal envelope spends above a network-specific threshold, R_{th} , and is given by,

$$ANFD = 1/\rho * f_T\sqrt{2\pi(1+\mu^2)} \qquad (5)$$

where $\rho = R_{th}/R_{rms}$ is the ratio between the transmission threshold and the root-mean-square power of the received signal f_T is the maximum Doppler shift of the transmitter.μ is the ratio of the receiver velocity to that of the transmitter where v_R and v_T are the receiver and transmitter node velocities, respectively.

$\mu = v_{R/} v_T$ (6)

$R_{rms=}$”$G_o d^{-\alpha}$ (7)

$f_{T=}\ f_o\ v_T/c$ (8)

f_o is the transmitter signal carrier frequency c is the speed of electromagnetic radiation.

It can be surmised from (5) that the value of the ANFD is high for low-transmission threshold (low ρ), and decreases with an increase of μ or ρ. Further, increased node mobility (captured by v_R and v_T) would cause a corresponding decrease in the ANFD due to the increased rate of signal fluctuations and that an increased link distance would cause a decrease in ANFD due to a greater path-loss influence.

The average fading duration (AFD), is the average length of time that the signal envelope spends below R_{th}.

$$AFD = (e^{\rho 2} - 1)/\rho {}^* f_T\sqrt{2\pi(1+\mu^2)} \qquad (9)$$

3.3 Phases in CA-AOMDV

There are two main phases in this protocol. They are route discovery and route maintenance.

In *route discovery phase,* CA-AOMDV uses the ANFD according to the mobile-to-mobile channel model as a measure of link lifetime. The path duration, D, is defined as the minimum ANFD over all hops in the path,

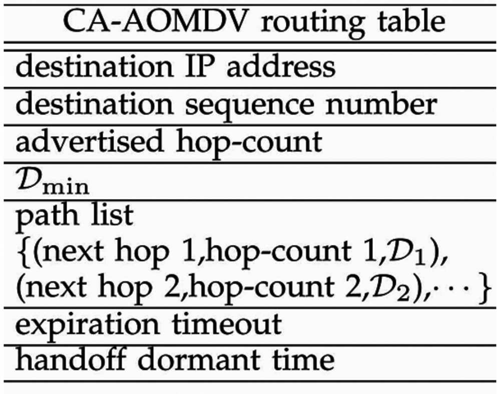
$$\mathcal{D} \triangleq \min_{1 \leq h \leq \mathcal{H}} \mathrm{ANFD}_h, \qquad (10)$$

where *h* is link number, and *H* is number of hops in the path. Node speed and direction in RREQ header are implemented and updated at each intermediate node. Thus the all the necessary information required for calculating the ANFD is available via the RREQs. Minimum distance over all paths between a given nodes is also can be calculated. This can be used as part of the cost function in path selection and is given by,

$$\mathcal{D}_{\min}^{i,d} \triangleq \min_{\zeta \in \mathrm{path\_list}_i^d} \mathcal{D}_\zeta, \qquad (11)$$

where $\mathrm{path\_list}_i^d$ the list of all saved paths between nodes n_i and $n_{d.}$ If a RREQ or RREP for n_d at n_i, from a neighbor node, n_j, has a higher destination sequence number or shorter hop-count than the existing route for n_d at n_i. However, if the RREQ or RREP has a destination sequence number and hop-count equal to the existing route at ni but with a greater $D_{min}^{i,d}$, the list of paths to n_d in n_i's routing table is updated.

The routing table structures for each path entry in AOMDV and CA-AOMDV are shown in figure 1 and 2



CA-AOMDV routing table
destination IP address
destination sequence number
advertised hop-count
$\mathcal{D}_{\text{min}}$
path list $\{$(next hop 1,hop-count 1,$\mathcal{D}_1$), (next hop 2,hop-count 2,$\mathcal{D}_2$),$\cdots\}$
expiration timeout
handoff dormant time

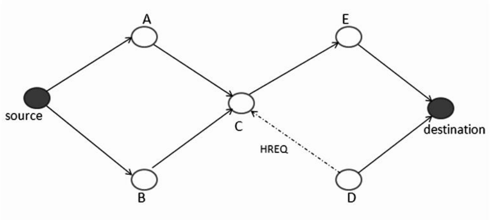
Fig. 2: Routing table structures for each path entry in CA-AOMDV

The handoff dormant time is the amount of time for which the path should be made dormant due to channel fading. It is set to the maximum value of the AFDs over all links in the path.

In route maintenance phase, to counter channel fading, handoff strategy using signal strength prediction is accomplished. When the predicted signal strength weakens the algorithm switches to a good link. All nodes have the information of past signal strengths, recording for each received packet, previous hop, signal power, and arrival time. For M number of past samples we consider specified discrete time interval, Δt. If packets are received at time intervals greater than Δt, sample signal strengths for the missed time intervals can be approximated by the signal strength of the packet closest in time to the one missed. If packets are received at intervals of shorter duration than Δt, some may be skipped.

3.4 Handoff in CA-AOMDV

The handoff process is implemented via a handoff request (HREQ) packet.When an intermediate node receives HREQ, it switches to a good alternate path from a faded path. The LMMSE prediction algorithm performs well when the prediction length is not too long. A suitable prediction length in (2) corresponds to the number of discrete time intervals, Δt, for transmission of a HREQ i, which can be approximated by using the data propagation time T_i^j from n_j to n_i.



⟶ : Forward routes

← – – : Fading link

HREQ: handoff request packet

Fig. 3: Handoff in CA-AOMDV. Node D has predicted a forthcoming fade for its link and has generated a HREQ. Node D forwards the HREQ to node C which may then be able to handoff to the path with node E as the next node.

It is given by

$$\Psi = \text{round}\,(T_i^j / \Delta t) \qquad (12)$$

where "round" is the integer rounding function. the signal strength is predicted at $t_0+\psi$ and $t_0+2\psi$ thresholds to enhance the robustness of the prediction process to errors. HREQ contains the following fields,<*Source IP address, Destination IP address, Source sequence number, Fade interval index, Long term fading indicator, AFD, and* V_T^{max}>Route handoff is initiated when a downlink node predicts a fade and transmits a HREQ to the uplink node. Let TR be the transmission range, assumed to be the same for all nodes. We know that R_{th} as the fade prediction threshold. If the prediction at $t_0+\psi$ is above R_{th} while that at $t_0+2\psi$ is below, the maximum transmitter velocity v_T^{max} ensuring signal strength above R_{th} at $t_0+\psi$.

3.5 Maintaining hand off table

Each node maintains a local handoff table to avoid duplicate hand off. Table includes: <*source IP address, source sequence number, destination IP address, and expiration timeout*>. Expiration timeout indicates when a path is out of the fade and expected to be available again. It is set to the maximum AFD of all currently faded links. When a node receives a HREQ, it checks its handoff table for a particular node n_s. The handoff table is updated if no entry exists for that n_s. The HREQ is dropped if any unexpired entry is found for that n_s with the same or higher source sequence number.

Any node receiving a nonduplicate HREQ checks for alternative paths to n_d. If not it propagates the HREQ. Otherwise, if it has one or more good alternative paths to the n_d, it marks the fading path indicated in the HREQ as dormant. Then the handoff dormant time is set in its routing table entry for that path to the AFD recorded in the HREQ. The HREQ is then dropped. If a fade is predicted on the active path, a nondormant alternative path to n_d is then adopted prior to the onset of link failure.

IV. Results and Analysis

In the system model, let us consider N no. of nodes area of side length 2S.Average number of hops (H) between 2 nodes, with transmission range $T_{R.}$

H=S (“2+ln (1+”2))/3T_R (13)

Average number of hops before encountering broken link is (H+1)/2. With C connections at any time, and n neighbors, average number of connections over a given link is B=2cH/nN.

AOMDV Multiple Path System Lifetime is Z_A. Let us assume all paths have L links. System is up as long as any of the N_p paths are still up (though once down they are discarded).

$$\begin{aligned}\Pr\{Z_A < t\} &= P_r\{(Z_{p_1} < t) \cap (Z_{p_2} < t) \cap \cdots \cap (Z_{p_{N_p}} < t)\} \\ &= \prod_{i=1}^{N_p} P_r\{Z_{p_i} < t\} = \prod_{i=1}^{N_p} F_{Z_{p_i}}(t) \\ &= (1 - e^{-\lambda_p t})^{N_p}.\end{aligned} \tag{14}$$

Expected lifetime of AOMDV multiple path system a”ANFD

$$E\{Z_A\} = \frac{N_p}{\lambda_p} \sum_{k=0}^{N_p - 1} (-1)^{N_p - k - 1} \binom{N_p - 1}{k} \frac{1}{(N_p - k)^2}. \tag{15}$$

The CA-AOMDV system is down only when all paths are down.

$$\begin{aligned}\Pr\{Y_C > t\} &= \prod_{i=1}^{N_p} P_r\{Y_{p_i} > t\} = \prod_{i=1}^{N_p} \left(1 - \prod_{\ell=1}^{L} P_r\{Y_\ell < t\}\right) \\ &= \prod_{i=1}^{N_p} \left(1 - \prod_{\ell=1}^{L} F_{Y_\ell}(t)\right) = [1 - (1 - e^{-\gamma t})^L]^{N_p}.\end{aligned} \tag{16}$$

Expected System Downtime a”AFD

$$\begin{aligned}E\{Y_C\} = \frac{N_p L}{\gamma} &\sum_{k=0}^{N_p - 1} (-1)^{N_p - k - 1} \binom{N_p - 1}{k} \\ &\sum_{i=0}^{L(N_p - k) - 1} (-1)^{L(N_p - k) - 1 - i} \binom{L(N_p - k) - 1}{i} \\ &\frac{1}{(L[N_p - k] - i)^2}.\end{aligned} \tag{17}$$

CA-AOMDV Multiple Path System Lifetime is given by ANFD in terms of AFD.

$$\mathrm{AFD} = \frac{\Pr(\text{channel is in a fade})}{\text{Level Crossing Rate}}$$

$$\begin{aligned}\mathrm{ANFD} &= \frac{\Pr(\text{channel is not in a fade})}{\text{Level Crossing Rate}} \\ &= \frac{1 - \Pr(\text{channel is in fade})}{\Pr(\text{channel is in fade})} \mathrm{AFD}\end{aligned}$$

Probability that a path is down is the probability that at least one link is in a fade. Recall that signal strength of a link has Rayleigh distribution, with parameter, ρ. Based on the Rayleigh distribution of the link gains, probability CA-AOMDV system in fade is

$$\Pr(\text{system in fade}) = \prod_{i=1}^{N_p}\left(1 - \prod_{\ell=1}^{L} e^{-\rho^2}\right) = \left(1 - e^{-L\rho^2}\right)^{N_p}. \tag{18}$$

So, if Z_C is CA-AOMDV system lifetime

$$E\{Z_C\} = \frac{1 - (1 - e^{-L\rho^2})^{N_p}}{(1 - e^{-L\rho^2})^{N_p}} E\{Y_C\}. \tag{19}$$

This new theoretical result allows us to compare the theoretical lifetimes of multiple path systems with and without reuse.

4.1 **Varying Node Mobility**

We now compare AOMDV and CA-AOMDV with respect to node mobility.

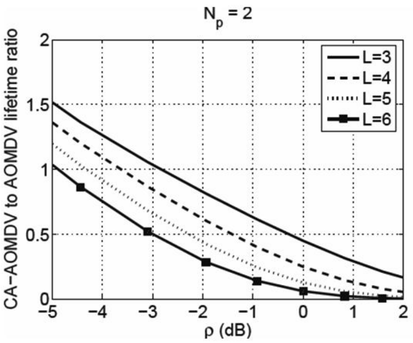


Fig. 4: Ratio of multiple path system lifetimes for CA-AOMDV to AOMDV for increasing values of link fading threshold parameter ρ.

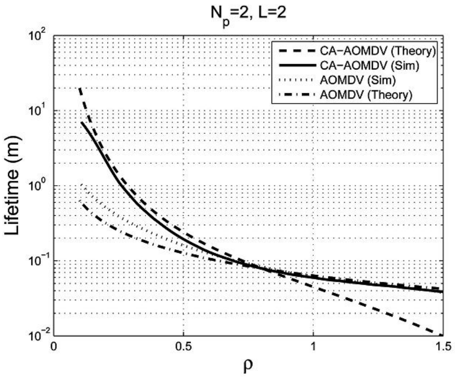


Fig. 5: Theoretical and simulated multiple path system lifetimes, in meters, for Np = 2 and L = 2 for CA-AOMDV and AOMDV.

4.1.1 Throughput

Throughput decreases with increased node mobility, with CA-AOMDV outperforming AOMDV, particularly, in the mid-range mobilities, with significant performance increases realized as shown in figure 6. At extreme mobilities, the throughput performances vary less and the advantages of CAAOMDV are greater with smaller network area (shorter path lengths) as previously noted. At low mobilities, path characteristics vary less quickly and the advantages of handoff in CA-AOMDV are less.

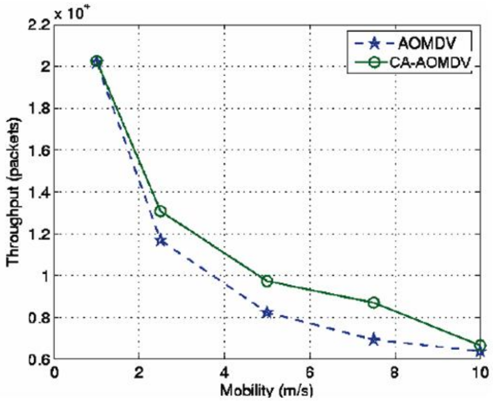


Fig. 6: Throughput Vs Mobility

V. Conclusions

A channel-adaptive routing protocol, CA-AOMDV, which is the extension of AOMDV, based on the proposed routing metric, is introduced which utilizes the average nonfading duration, combined with hop-count, to select stable links. In CA-AOMDV, predicted signal strength and channel average fading duration are combined with handoff to combat channel fading and improve channel utilization. A new theoretical expression for the lifetime of the multiple reusable path system used in CA-AOMDV is derived. Results show that CA-AOMDV is better than AOMDV.

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