Development and Performance Characterization of Enhanced AODV Routing for CBR and TCP Traffic

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Abbreviations

- MANETs - Mobile Ad hoc Networks
- DSR - Dynamic Source Routing
- AODV - Ad hoc On-demand Distance Vector Routing
- DSDV - Destination Sequenced Distance Vector Routing
- OLSR - Optimized Link State Routing
- ZRP - Zone Routing Protocol
- RREQ - Route Request
- RREP - Route Reply
- RERR - Route Error
- LLACKs - Link Layer Acknowledgements

Presentation Outline

- Introduction & Motivation
- Background On MANET Routing Protocols
- Link Breakage Prediction Algorithm
- Design of EAODV
- Performance Evaluation
- Conclusions & Future Work

Introduction & Motivation

- MANETs - Autonomous system of mobile routers connected by wireless links
- Network topology may change rapidly and unpredictably
- MANETs find use in scenarios where a centralized command center is infeasible and undesirable – e.g. battle field communication, disaster management scenarios, etc.
- Key challenge is to devise efficient methods to ensure route availability, while incurring minimal routing overhead

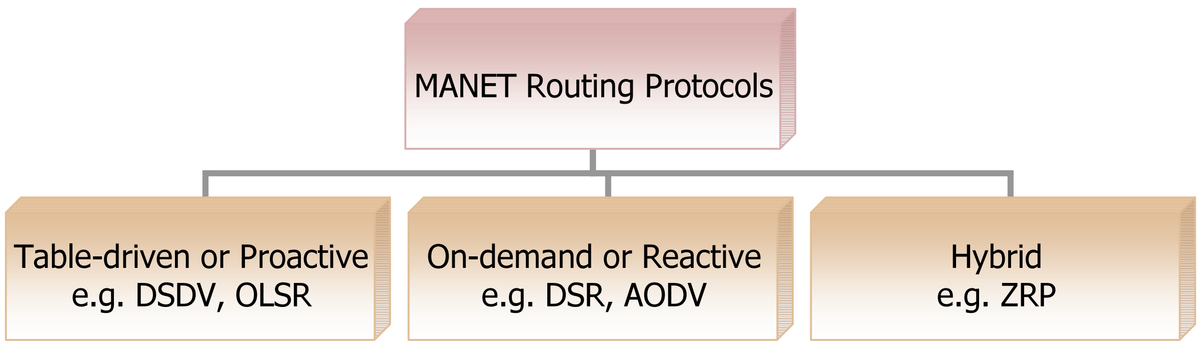
Introduction & Motivation (contd…)

- Most of the existing MANET routing protocols reside in the network layer
- Link state or received signal strength information is largely ignored
- Can improve performance if signal strength information used
- Need for a cross-layer design

Background on MANET routing Protocols

- Classification of MANET Routing Protocols
- Comparison between Proactive and Reactive protocols
- Overview of DSR and AODV

MANET routing protocols classification



MANET routing protocols classification (cont…)

- Proactive protocols – always have routes to destinations, if possible
  - Possibly lesser end-to-end delay, but higher control overhead
- Reactive protocols – attempt to discover routes whenever needed
  - Possibly lesser control overhead, but higher end-to-end delay
- Hybrid protocols – combine both proactive and reactive protocols
  - Only slight performance advantage because do not make use of link state information
- Each protocol suited better for certain scenarios

Overview of DSR and AODV

- Existing simulation results conclude that reactive protocols (DSR and AODV) offer overall better performance
- DSR vs. AODV
  - DSR outperforms AODV in less “stressful” scenarios (smaller nodes, lower load and/or mobility)
    - Source routing in DSR expensive with larger number of nodes and higher load
  - AODV outperforms DSR in more “stressful” scenarios (more load, higher mobility, etc.)

DSR

- Packets source routed using dynamically learned routes from route cache
- Route discovery process
  - On-demand flooding if no route in cache
- Route maintenance procedure
  - Source initiates route discovery when informed of link breakage
- Cache expiry methods have direct impact on performance
- Can operate over unidirectional links due to source routing

AODV

- Combination of DSDV and DSR
- Route discovery process
  - Similar to DSR, but no source routing; instead nodes "remember" only next hops (routing tables)
    - Overhead per packet reduced when compared to DSR due to absence of source routing
  - Same message types as in DSR (RREQ, RREP, RERR)
- Route maintenance procedure
  - Intermediate nodes *may* attempt "local repair" to replace broken routes
  - Else, upstream flooding
  - Route lifetime extended after every successful use of the route
- Requires bi-directional links, unlike DSR

Link breakage prediction algorithm

- Motivation
- Radio Propagation models
- Prediction algorithm developed
- Reliability of the prediction algorithm

Motivation

- Most MANET routing protocols ignore link state information except while using LLACKs to determine link breakage
  - Route cache/tables refreshed based on frequency of route usage
- Can argue (intuitively) that link state information will help intelligent (proactive) scheduling of route maintenance
  - Strong link, Weak link, etc…
- Benefits two fold
  1. No route discovery delay
  2. Can avoid costly LLACKs to determine link breakage

Radio Propagation models

- Two radio propagation models: Friis and Two-Ray Ground
- If *'d'* less than cross-over distance (86.14 m, in our case) then Friis model holds true, otherwise Two-Ray Ground model is better
- All antennas in simulation model assumed to have a transmission range of 250 m
- Hence, used the more conservative Two-Ray Ground model for all cases
- Equation for received power simplifies to:

$$P_r = k \frac{P_t}{d^4} \quad \text{where:} \quad k = G_t . G_r . (h_t . h_r)^2 \text{ is a constant}$$

- With knowledge of P_r and P_t, d can be easily computed

Heuristic prediction algorithm

Always assume nodes moving ***radially outward***.

Initially, $V = V_{prev} = V_{max}$ m/s , $d_{prev} = 0.0$ m

1. $v = \left| \frac{d - d_{prev}}{t - t_{prev}} \right|$

2. $V = (w) * v + (1-w) * V_{prev}$

   - w based on ratio of time since last sample ($\Delta t = t - t_{prev}$) and average sample interval T
   - Time dependency of w ensures quick adaptation to changes

3. $t_{break} = \left[\frac{d_{\max} - d}{V} \right]$

4. $V_{prev} = V; d_{prev} = d$

- Algorithm reset after TIME_USELESS (50) seconds

Reliability of the prediction algorithm

- Predicted value of $\boldsymbol{t}_{break}$ can be used by any ad hoc routing protocol
  - Hence, placed the prediction algorithm in the MAC layer
- Accuracy suffers in some cases
  - 'False predictions' in high mobility, low load scenarios
- False predictions can be reduced by tuning implementation parameters
- Accuracy increases with increase in rate of packets received – i.e. in high mobility, high load scenarios

Design of EAODV

- Construction of Hybrid Protocols
- EAODV implementation details
- Flowchart of EAODV

Construction of Hybrid Protocols

1. Introduce proactivity in a reactive protocol
   - Expect reduction in end-to-end delay, for increase in overhead

2. Introduce reactivity in a proactive protocol
   - Expect reduction in overhead, for increase in end-to-end delay

- Given the superior performance of reactive protocols, chose to construct a hybrid protocol using (1)

- Need an interface to MAC layer to assess state of link before initiating proactivity

EAODV implementation details

- Chose AODV because it performs better at higher load
  - higher load also good for prediction
- Chose ns-2 simulator (v 2.1b9a) for implementation and testing
  - Widely used by MANET research community – fair comparison possible
  - Rich library of wireless routing protocols
- Basic simulation event/unit is a “packet”
  - Henceforth, *packet* used interchangeably with MAC *frame*, IP *datagram*, and TCP *segment*

MAC layer implementation in EAODV

- Compute distance ‘d’ from neighbor from incoming MAC frames
- Prediction algorithm predicts t_{break} using ‘d’
- Can determine if neighbor moving *relatively* INWARD, OUTWARD or STATIC by looking at past ‘d’ values
- Link status marked ACTIVE or IDLE
  - ACTIVE if any packet received/sent
  - IDLE if no packet for *max(4*T, IDLE_PERIOD* (15) *)* seconds
- Node direction, Link status concluded only after MIN_SAMPLES (4) observations
- Maintained a table with these pieces of information for each neighbor

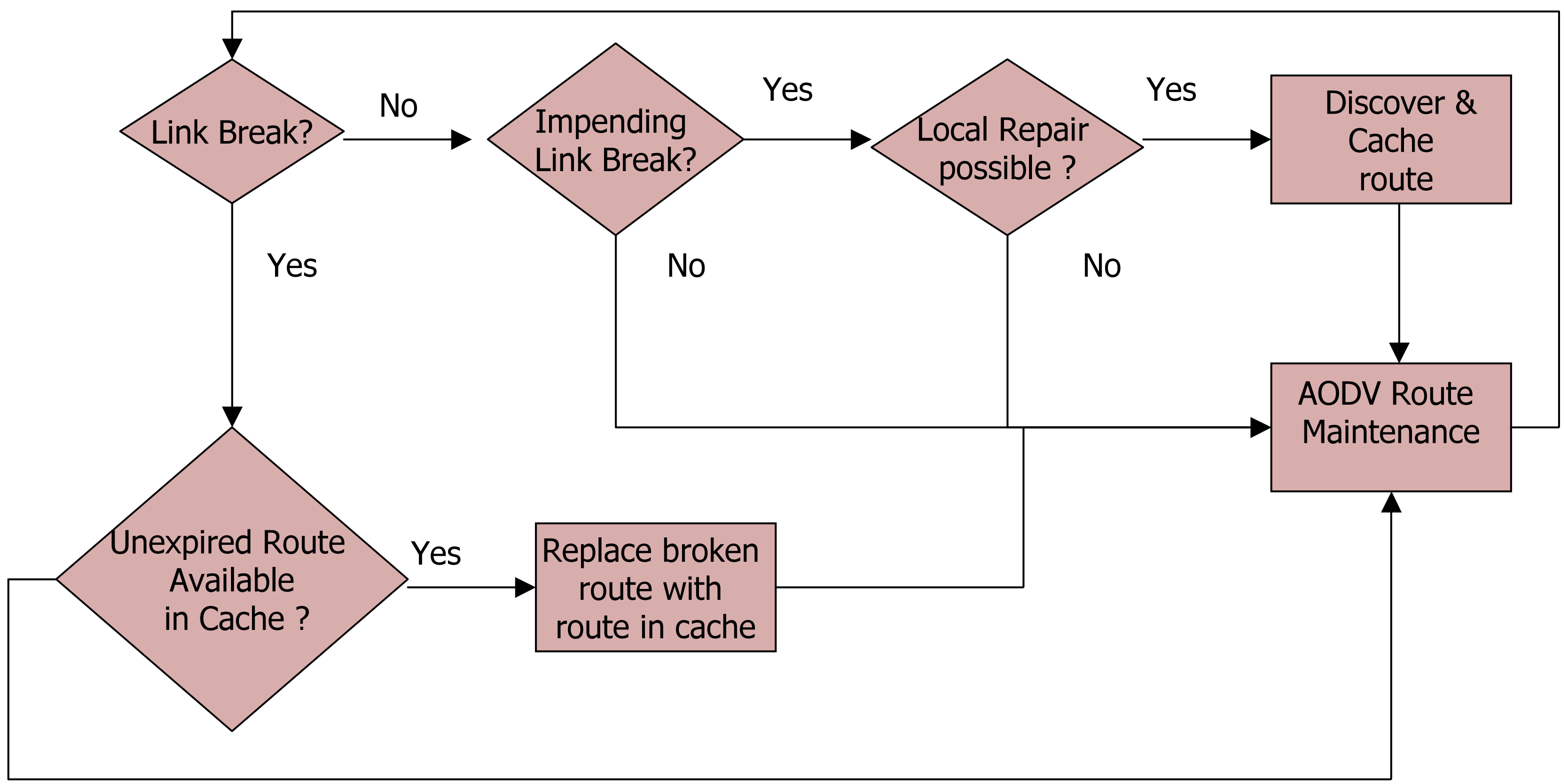
AODV layer implementation in EAODV

- Each neighbor monitored once every 0.5 seconds for breakage
  - Only ACTIVE links connecting neighbors moving OUTWARD considered – susceptible candidates for breakage
- Impending breakage of any link triggers proactive route discovery (ACTIVE routes only)
  - If *MIN_THRESHOLD (0.03)* $< t_{break} <$ *BREAK_THRESHOLD (0.15)* , then proactive route maintenance initiated (includes proactive *local repair*)
  - Else, link breakage allowed to happen, and normal AODV route error handling mechanisms take over

AODV layer implementation (cont…)

- Proactively discovered routes discarded from cache after ACTIVE_ROUTE_TIMEOUT(10) seconds
- Replacing "broken" routes
  - Link assumed broken if either t_{break} has elapsed or through LLACKs in case of erroneous prediction of t_{break}
    - To determine link breakage, t_{break} method better than LLACKS method
    - Avoids link layer retransmission, and reduces end-to-end delay further
  - If link breaks before ACTIVE_ROUTE_TIMEOUT seconds, route from cache used
  - Absence of route in cache triggers normal AODV error handling

Flowchart of EAODV



Performance Evaluation

- Performance metrics
- Simulation setup
- Simulations with CBR traffic
- Simulations with TCP traffic
- CBR vs. TCP simulations

Performance Metrics

- Mean end-to-end delay (*e2e*)
  - average delay per packet
- Control bits per data bit transmitted (*cpd*)
  - ratio of total AODV overhead (RREQ, RREP, RERR) to total data transmitted
- Packet delivery ratio (*pdr*)
  - ratio of packets delivered to packets generated (CBR traffic only)
- Throughput (*tp*)
  - packets delivered per second (TCP traffic only)
- Average number of hops per packet (*hops*)

Simulation Setup

- Two node mobility models
  - Random Waypoint Model (RW model)
    - 1500 m x 1500 m simulation area
    - 2 degrees of freedom – max velocity(*mv*) and max pause time (*mp*)
    - default values: *mv* - 10 m/s, *mp* - 0 s (continuous mobility)
      - *mv* varied as 1, 5, 10, 15 and 20 m/s
      - *mp* varied as 0, 250, 500, 750, 1000, 1500, and 2000 s
  - Manhattan Grid model (MG model)
    - 1000 m x 1000 m simulation area
      - Simulation area reduced from RW model to reduce degree of network partitions
    - mobility varied across turn probability(*pt*) & pause probability (*pp*)
    - default values: *mv* – 10 m/s, *mp* – 120 s, *pt* – 0.25, *pp* – 0.0
      - *pp* varied as 0, 0.25. 0.5, 0.75, and 1.0
      - *pt* varied as 0, 0.25, 0.5, 0.75, and 1.0
- In each model, 50 nodes, with mobility captured after 3600 s warm-up time

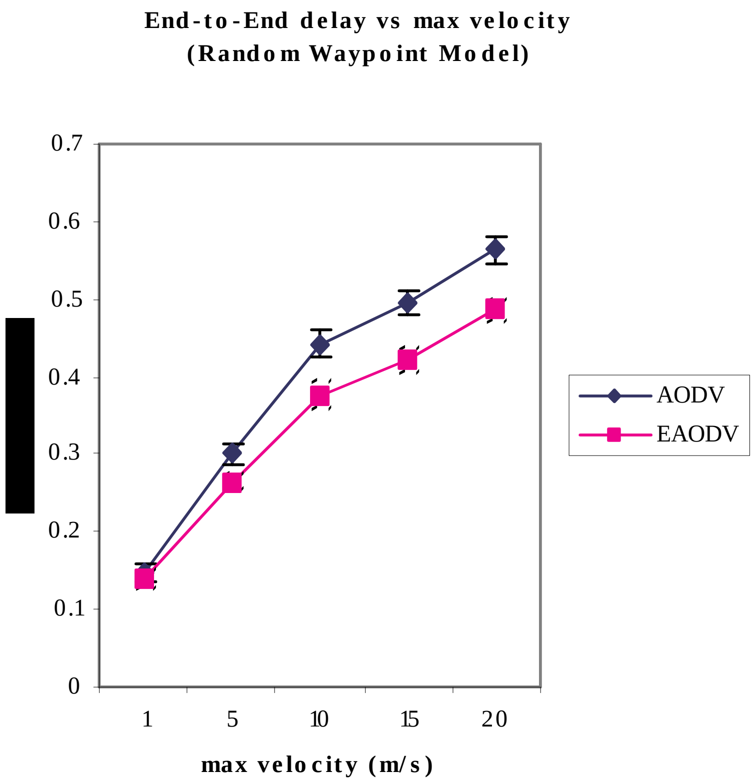
Simulations with CBR traffic

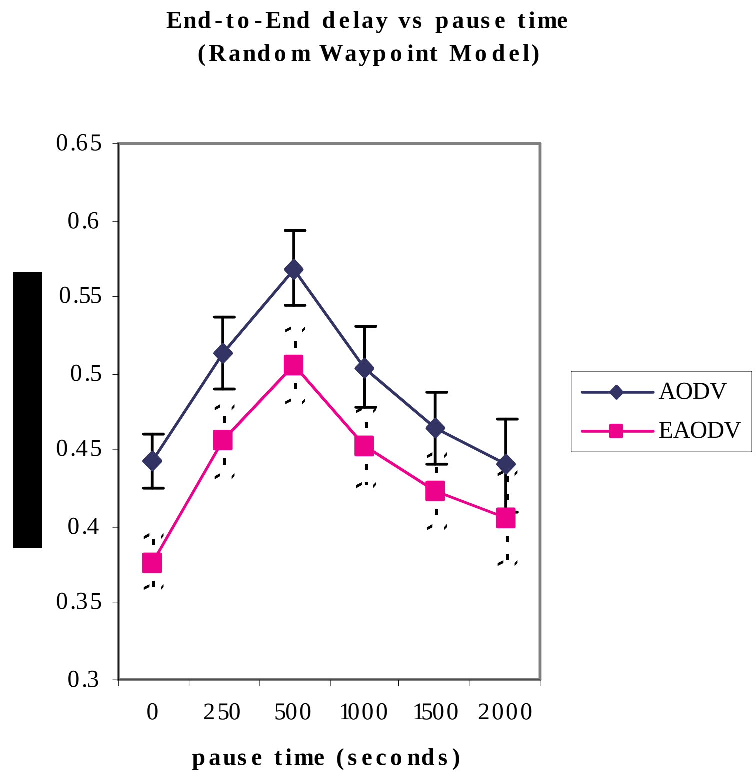
- 20 CBR connections, 512-byte packets, default packet rate – 1 packet/sec (4Kbps), default simulation duration - 2000 s
  - Packet inter-arrival time varied as 0.1, 0.25, 0.5, 1.0, 2.0 and 4.0 s
    - Simulation duration adjusted so that packet generation is about 40,000 packets
- Both RW and MG mobility pattern used
- Performance metrics considered: *e2e*, *pdr*, *cpd* and *hops*
- Each data point averaged over 50 simulation runs
- Results reported with 90% confidence interval

CBR Delay Results

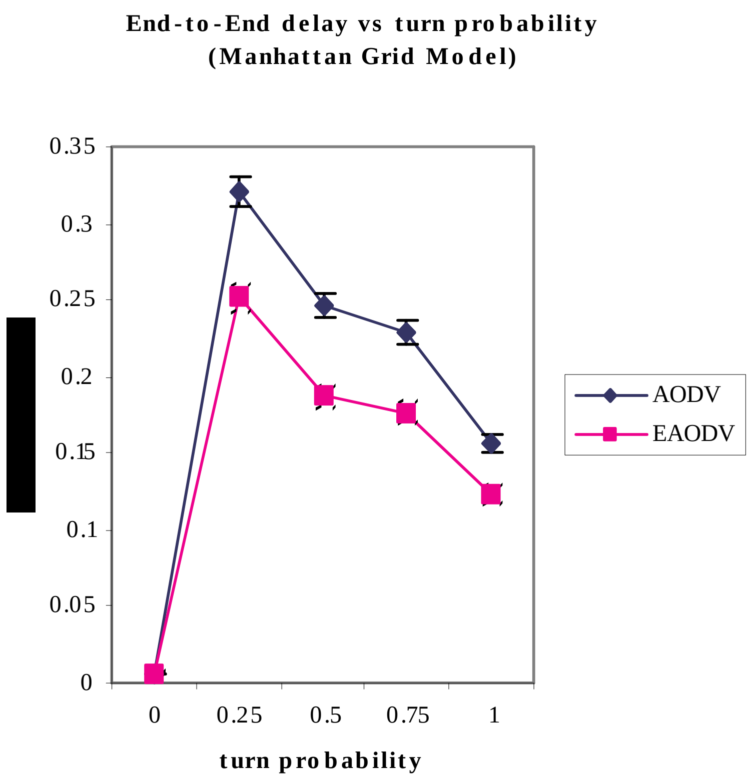
- *e2e* in EAODV significantly reduced when compared to AODV
  - Reduction in *e2e* mainly due to proactive behavior induced in EAODV due to cross-layer interactions
    - In case of a link failure, queued data packets forwarded without any (Route discovery) delay using proactively discovered route in cache
  - Improvement in *e2e* increases with increasing mobility (higher velocity, lower pause time, higher turn probability, etc.)
    - Higher mobility generates higher network control traffic – increased accuracy in prediction

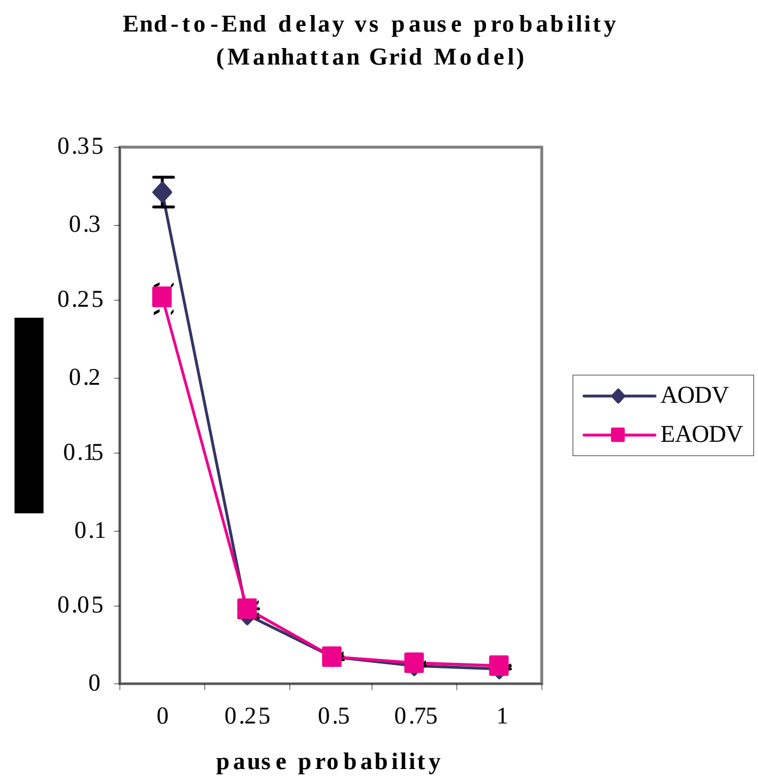
CBR Delay Results: RW model





CBR Delay Results: MG model





Other Results

- *cpd* increase only marginal in EAODV when compared to AODV
  - *cpd* good indicator of prediction algorithm performance
    - 100% accurate prediction algorithm means no unwanted proactivity (inevitable route discovery advanced in time) - *cpd* in EAODV comparable to AODV
  - Increase due to approximations in prediction algorithm (e.g.) assuming radial outward motion of nodes
- *pdr* decrease in EAODV very small
  - Again, decrease due to approximations in prediction algorithm
- *hops* in EAODV always slightly higher than AODV
  - AODV always uses best available route, while EAODV uses best available route only *while* reactively discovered route exists
  - In spite of increase in number of hops, decrease in *e2e* achieved

CBR Results Summary

- Results indistinguishable for AODV and EAODV when load varied

- In EAODV, performance gains far outweigh penalties paid
  - Mean decrease in *e2e* : 11.95% in RW model, 19.94% in MG model
  - Mean decrease in *pdr :* 2.7 % in RW model, 1.45% in MG model

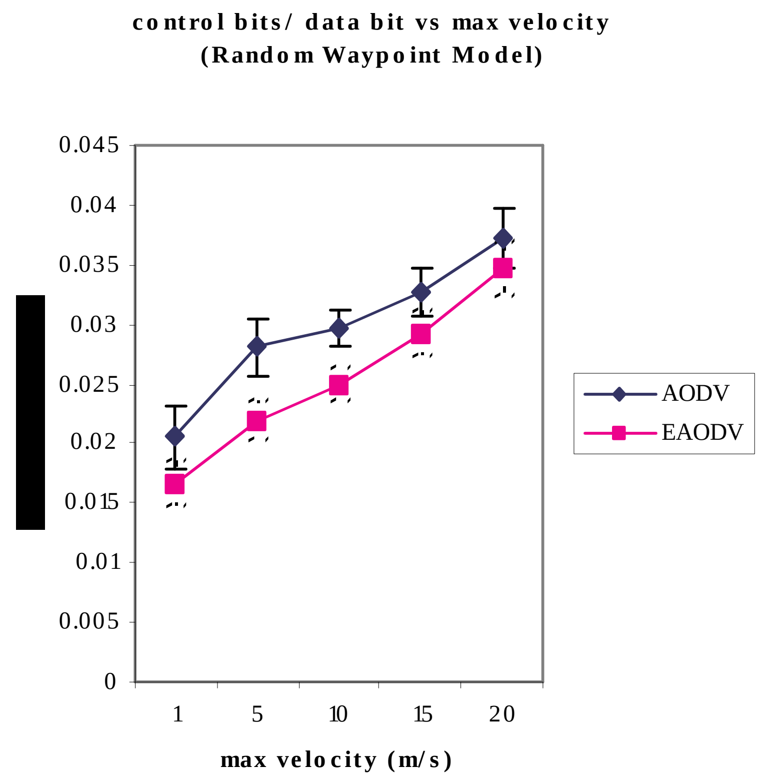
- Clearly, EAODV more beneficial when degree of mobility is higher i.e. when topology is quite transient

Simulations with TCP traffic

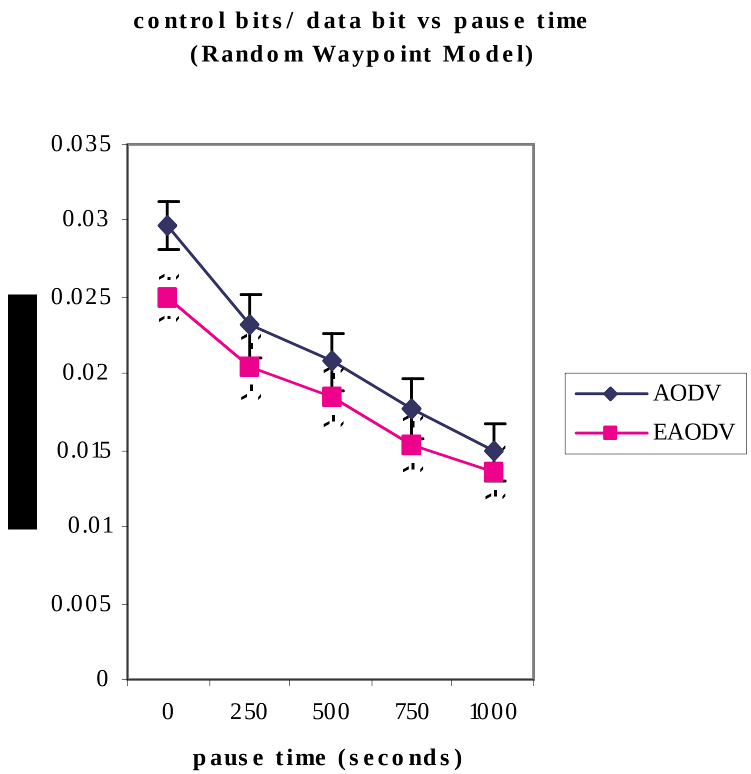
- 20 *TCP-Tahoe* connections transferring a file of infinite size
- 512-byte TCP segments
- Both RW and MG mobility models used
- Performance metrics considered: *cpd*, *e2e*, *tp* and *hops*
- Simulation duration is 1000 seconds
- Each data point averaged over 50 simulation runs
- Results reported with 90% confidence interval

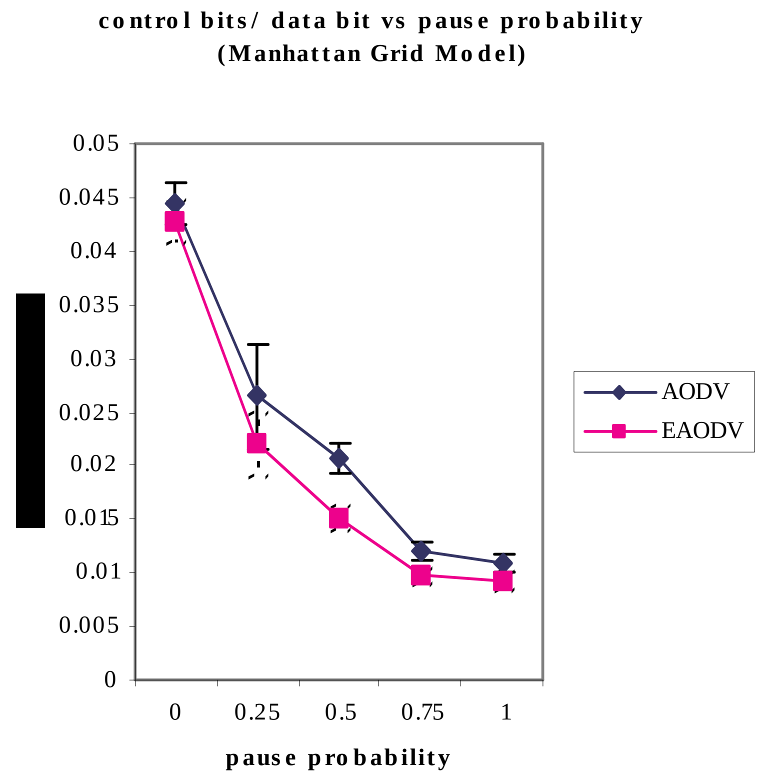
TCP Overhead Results

- *cpd* performance better in EAODV than AODV
  - Much higher packet generation rate in TCP (as opposed to CBR) increases accuracy of prediction algorithm – better *cpd* !!



TCP Overhead Results (cont…)





Other Results

- *e2e* performance in EAODV slightly better than AODV
  - Again, due to better prediction with TCP traffic
- *tp* and *hops* performance comparable for both AODV & EAODV

Some interesting results with TCP traffic

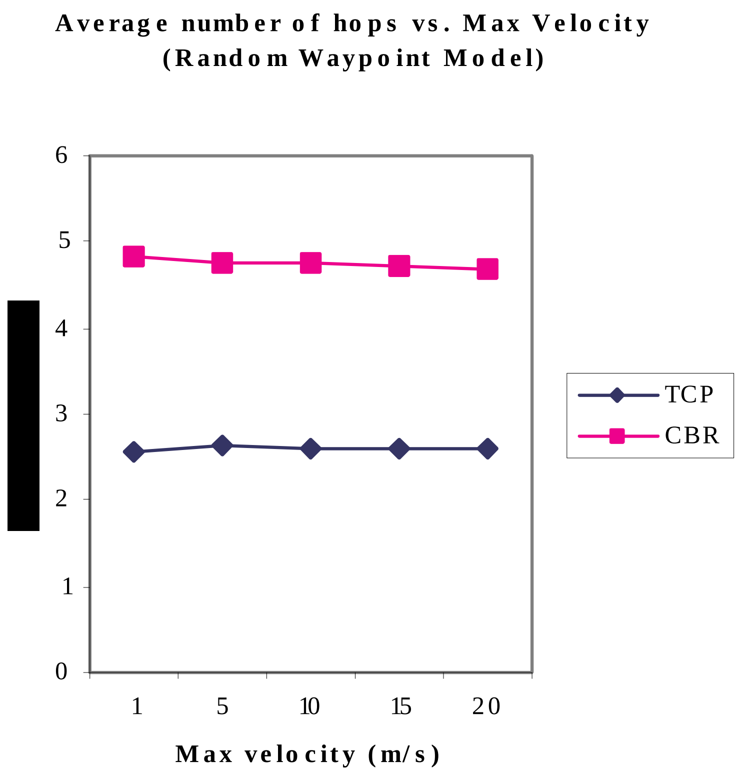
- *e2e* lower at higher velocities in RW model!!
  - reduced queuing delay due to reduced *tp* greatly offsets increased queuing delay due to increased control traffic at higher velocities

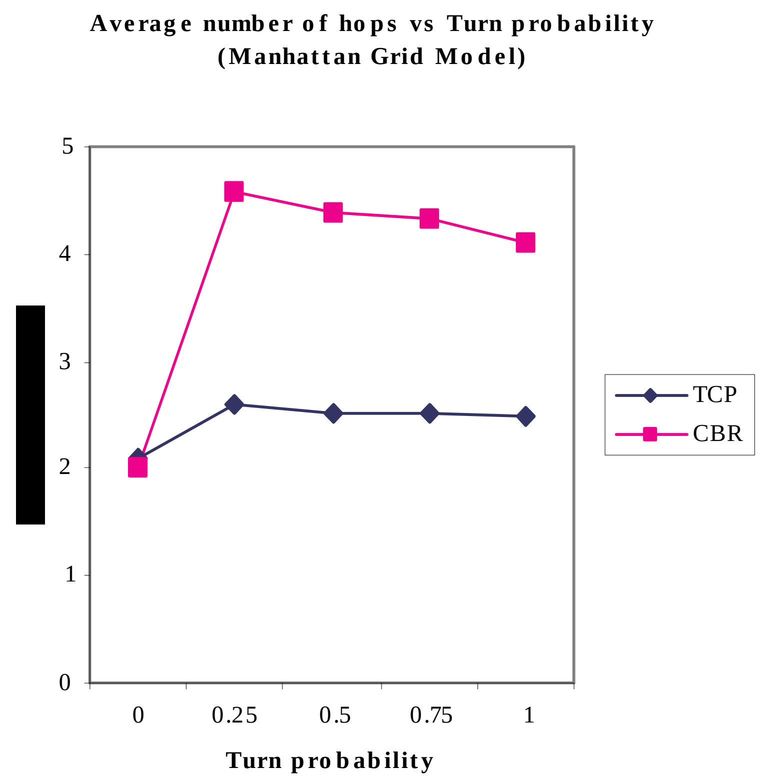
- *e2e* and *tp* performances degrade in highly stable topologies in MG model
  - Single channel communication model for IEEE 802.11 increases contention and collision of RTS/CTS/ACK frames at highly stable/connected topologies

CBR vs. TCP simulations

- *e2e* in TCP much lesser than CBR !!
  - Rate limiting property of TCP in action
    - maximum throughput when round-trip time (*rtt)* is lowest
    - In the absence of congestion, *rtt* directly dependent on number of hops traversed
    - Most of the packets in TCP generated when hop count to destination is smaller, ensuring smaller overall e2e
  - Packet generation in CBR is oblivious to *rtt* or *hops*, hence overall higher *e2e* when compared to TCP.

CBR vs. TCP simulations (cont…)





TCP Congestion Control Interaction

- TCP misinterprets increase in *rtt* due to link breakage as congestion and multiplicatively decreases congestion window L
  - Bad for throughput, especially in MANET topologies
- TCP should be able to distinguish between link breakage and congestion
- Still, reduction in congestion window needed; otherwise build-up at interface queues during link breakage can cause congestion
  - Can use an "additive decrease – additive increase" scheme during link breakage and "multiplicative decrease – additive increase" scheme during congestion

Conclusions & Future Work

- Summary of Contributions
- Conclusions
- Future Work

Summary of contributions

- Developed a prediction algorithm to predict link breakage time from signal strength information extracted from a received packet
- Implemented the prediction algorithm in the ns-2 simulator at the 802.11 wireless MAC layer
- Derived EAODV from AODV by suitably modifying AODV route maintenance and providing an interface for cross-layer interactions with the MAC layer
- Characterized the behavior of EAODV with CBR traffic, and compared performances of EAODV and AODV with CBR traffic sources
- Characterized behavior of EAODV with TCP traffic, and compared performances of EAODV and AODV with TCP traffic sources
- Compared CBR and TCP traffic performance with EAODV
  - Noted possible improvements in TCP

Conclusions

- For CBR traffic, EAODV is more beneficial at higher mobility scenarios
  - Better *e2e* performance, especially at higher mobility
  - Slight degradation in *cpd* and *pdr* performance
- For TCP traffic, EAODV performs slightly better than AODV in most cases
  - *cpd* and *e2e* almost always better
  - *Tp* slightly lesser
- For TCP running over Ad hoc networks, slight modifications in TCP may be required to increase TCP throughput

Future Work

- Rigorous testing of prediction algorithm for transient effects by introducing fading effects in the ns-2 packet corruption model
  - Breaks fundamental assumption that received power *always* reflects distance of separation
- Test suitability of EAODV for real time traffic with smaller packets
- TCP performance over ad hoc networks requires further study
- Modification of TCP congestion control for link breakage

Research Papers

"*Performance characterization of Enhanced AODV routing for CBR and TCP traffic*", Pradeepkumar Mani, David W. Petr

(under consideration at ICC-2004, Paris)

Thank you!!