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## Multipath Routing – A Cross-Layer Design Tool for QoS Provisioning in MANETs

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# Quality-of-Service in MANET

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- **The goal** is to support real-time (interactive) applications in mobile ad hoc networks with
  - “guaranteed” timely delivery
  - data protection against channel impairment
  - load balancing
- **Why this is a new problem? (i.e., QoS in MANET vs. QoS in infrastructure-based wireless networks)**
  - MANETs are multi-hop based
  - no infrastructure, no central entity
  - frequently changing topology with wireless connectivity

# *Effects of Mobility in MANET*

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## ➤ **Negative impact**

- Routes frequently break, leading to disruption in traffic interactivity
- Increased signaling overhead (e.g., due to route rediscoveries)
- Increased loss of packets in transit

## ➤ **Positive impact**

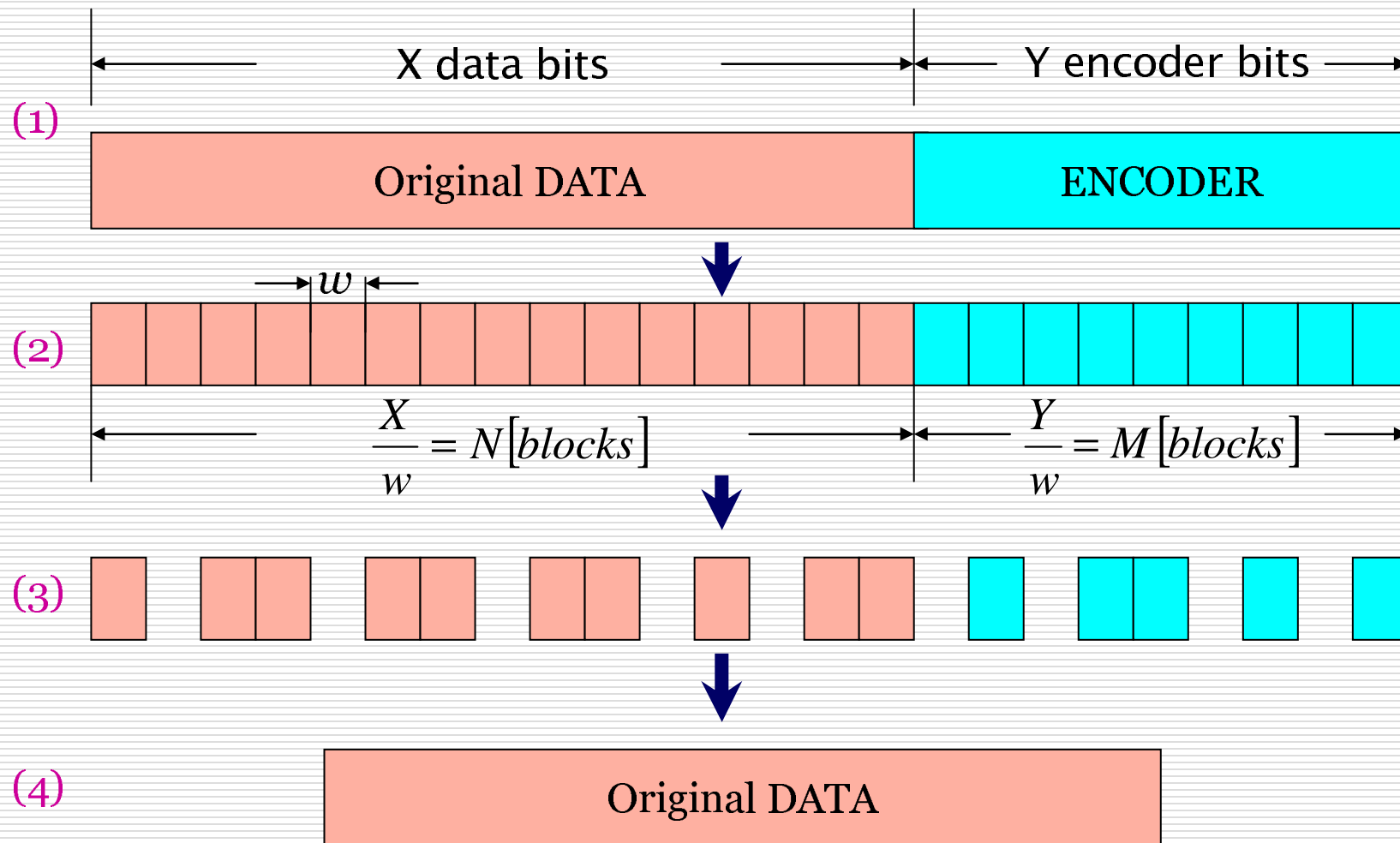
- Elimination of suboptimal route due to frequent route rediscovery
- Improvement in per-node capacity under certain mobility models [Grossglauser and Tse, 2002]

## *Multipath Routing in MANET*

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- *Multipath Routing* is one candidate for QoS provisioning in MANET
- It is implemented through the Diversity-Coding (DC)  
*[A. Tsirigos and Z.J. Haas, "Analysis of Multipath Routing - Part I: The Effect on the Packet Delivery Ratio," IEEE Trans. on Wireless Comm., vol. 3, no. 1, January 2004]*
- *Multipath Routing* can support numerous QoS features; for example:
  - improved path reliability (i.e., protection against frequent path breakages)
  - improved data transmission security in ad hoc networks  
*[Papadimitratos and Haas, 2003]*

# Principle of M-for-N Diversity Coding



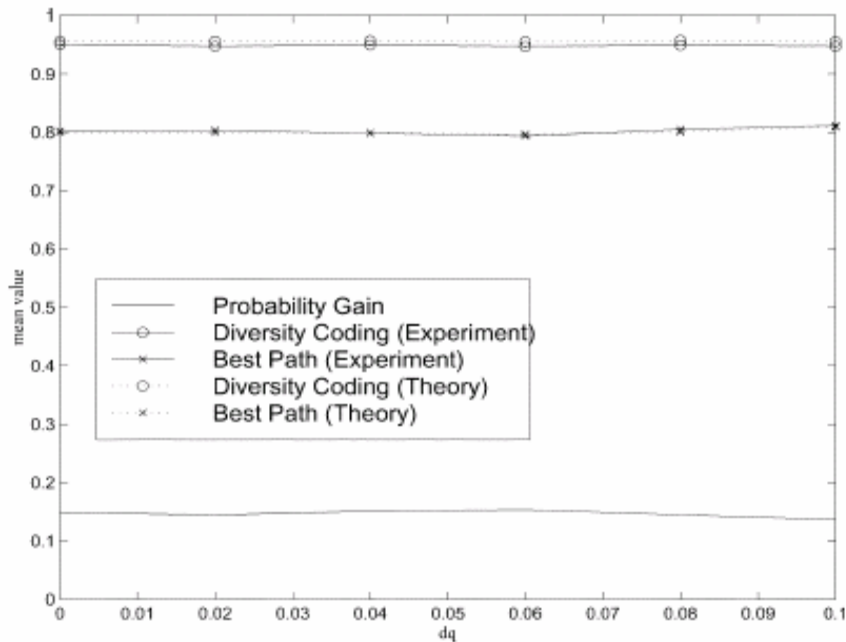
# *Diversity Coding based Multipath Routing*

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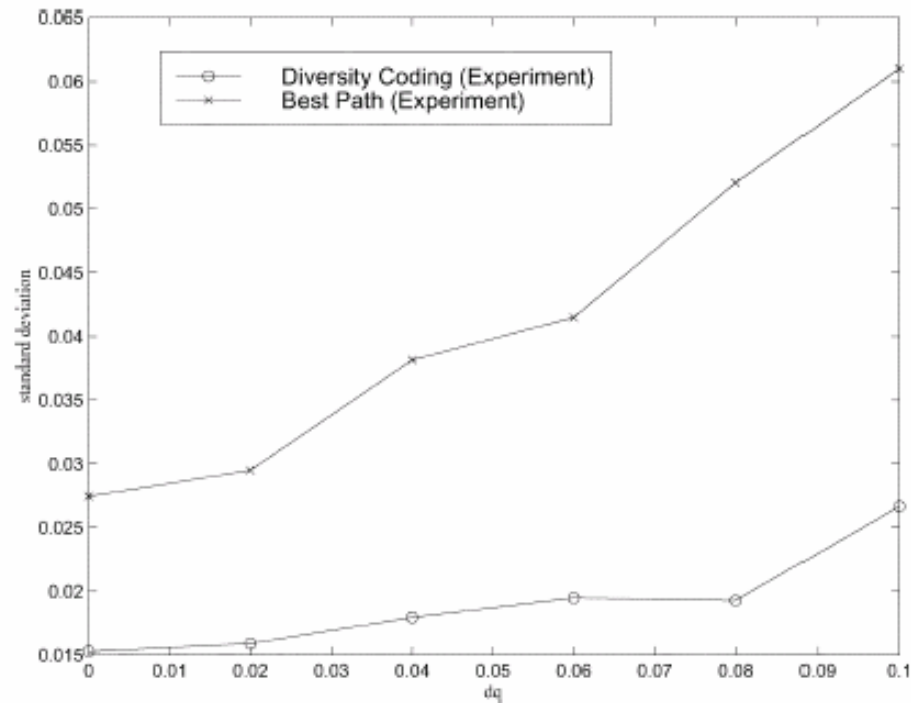
## Feature of *Diversity Coding* (DC)

- ❑ **Loss tolerance:** DC allows some block loss during transmission (up to  $M$  blocks in  $N:M$  *Diversity Coding*)
- ❑ **Data re-construction:** DC allows to fully re-construct original data at the destination
- ❑ **Block Design Objective:** to maximize the probability that the original data is fully re-constructed at the destination,  $P_{\text{succ}}$
- ❑ **Path selection:** to select the most reliable paths that achieve the above objective
- ❑ **Packet allocation:** to allocate more packets on more reliable paths (i.e., non-uniform packet allocation)

# DC-based Multipath vs. Single-path Routing (Independent Paths)



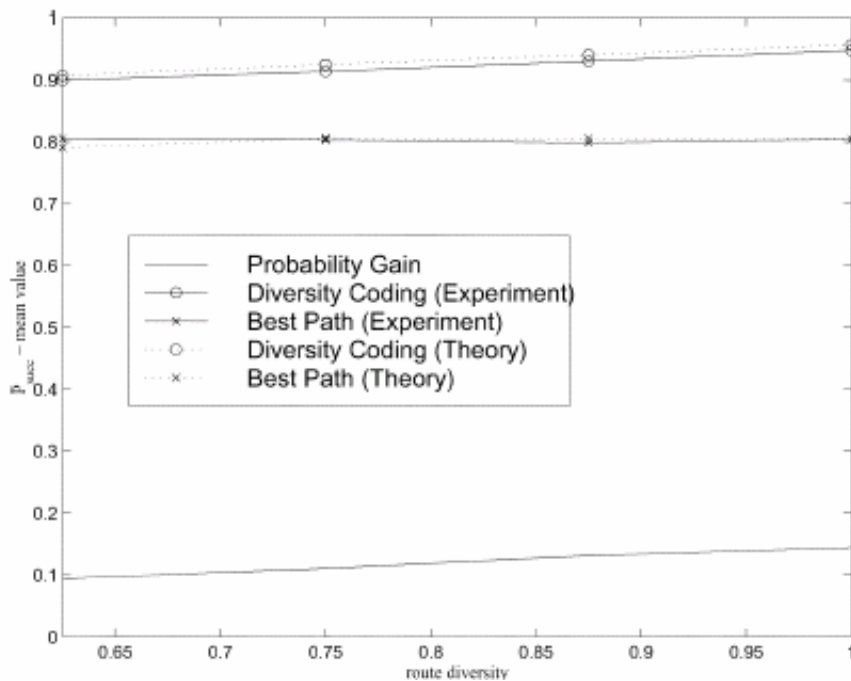
Mean  $P_{succ}$  and probability gain



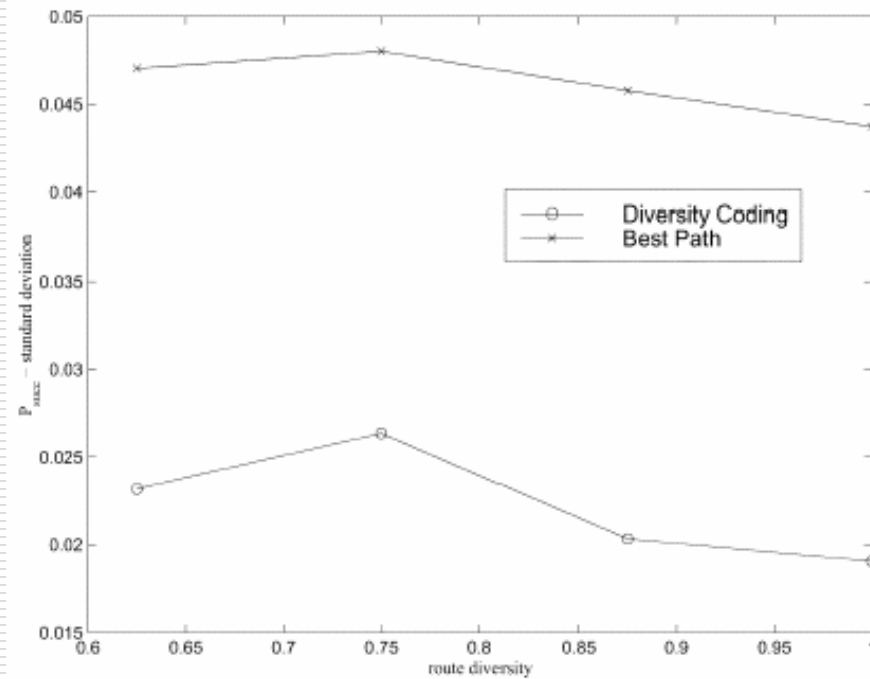
Standard deviation of  $P_{succ}$

Probability gain: the difference in mean  $P_{succ}$  between DC and single, best path routing

# DC-based Multipath vs. Single-path Routing (Correlated Paths)



Mean  $P_{succ}$  and probability gain



Standard deviation of  $P_{succ}$

Route diversity: the degree of correlation between the paths in the path set

# Use of Multipath Routing and DC for Secure Message Transmission in Ad Hoc Networks

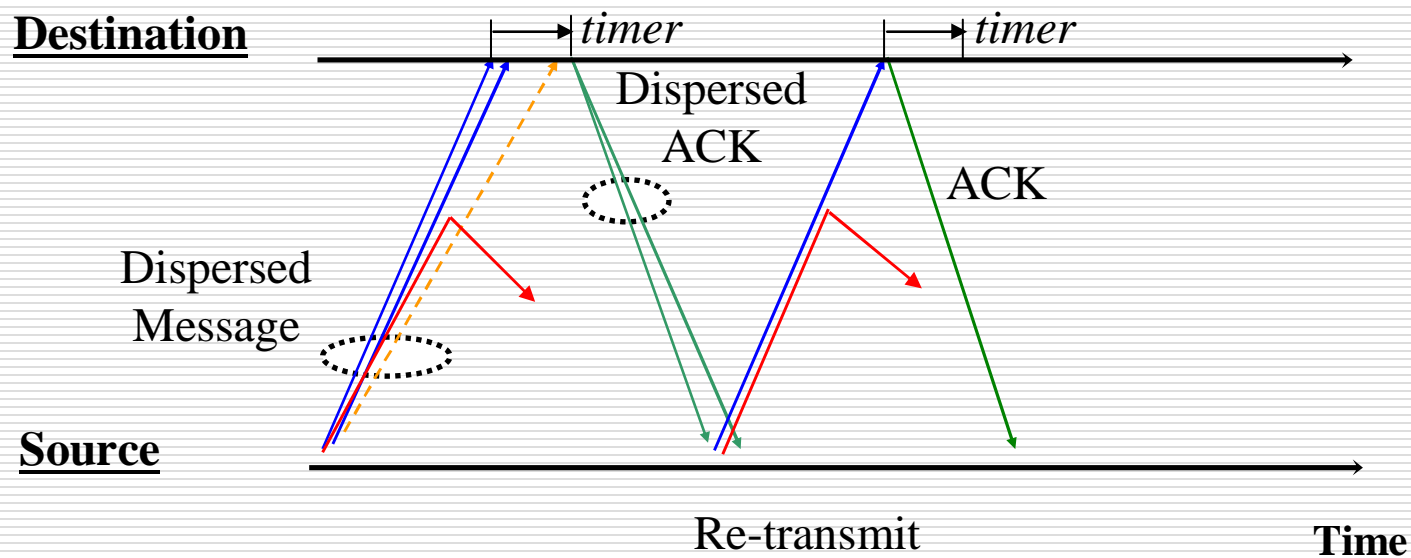
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- Supporting security in ad hoc networks is a major challenge, due to:
  - Lack of central entity (i.e., no single entity that every node trusts)
  - Frequent changes of network constituency and topology
- Multipath Routing with DC is used to support security by:
  - Dispersion of the transmitted data
  - Simultaneous usage of multiple, node-disjoint routes
  - Data integrity and origin authentication
  - End-to-end secure and robust feedback
  - Adaptation to the network conditions

The above scheme is called the *Secure Message Transmission (SMT)* protocol

# Transmission of a Message with *SMT*

An example of the use of Multipath Routing and DC for secure message delivery in *SMT*:



## Implementation of *SMT*

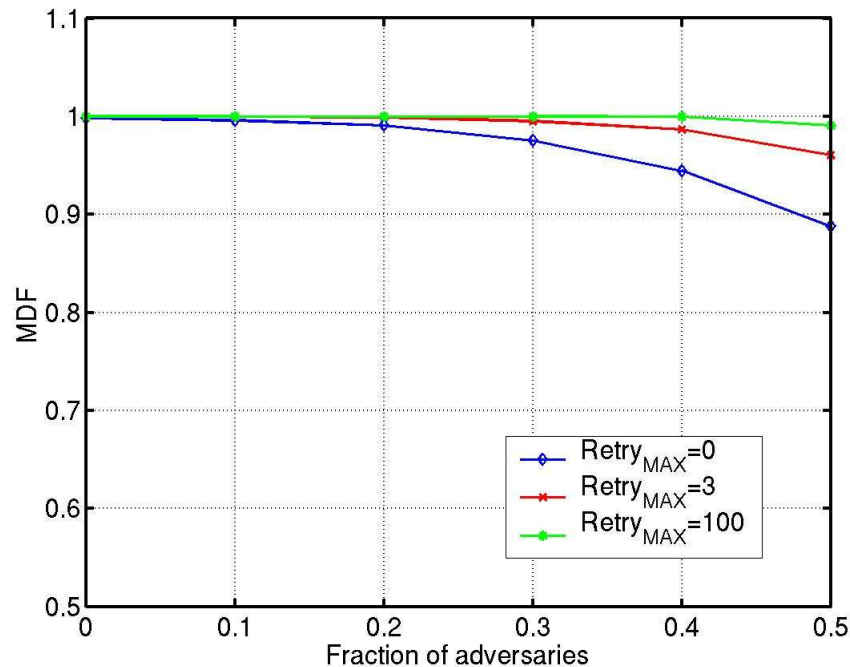
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- *SMT* operates on top of any secure routing protocol that can discover multiple routes (e.g., the *Secure Routing Protocol*)

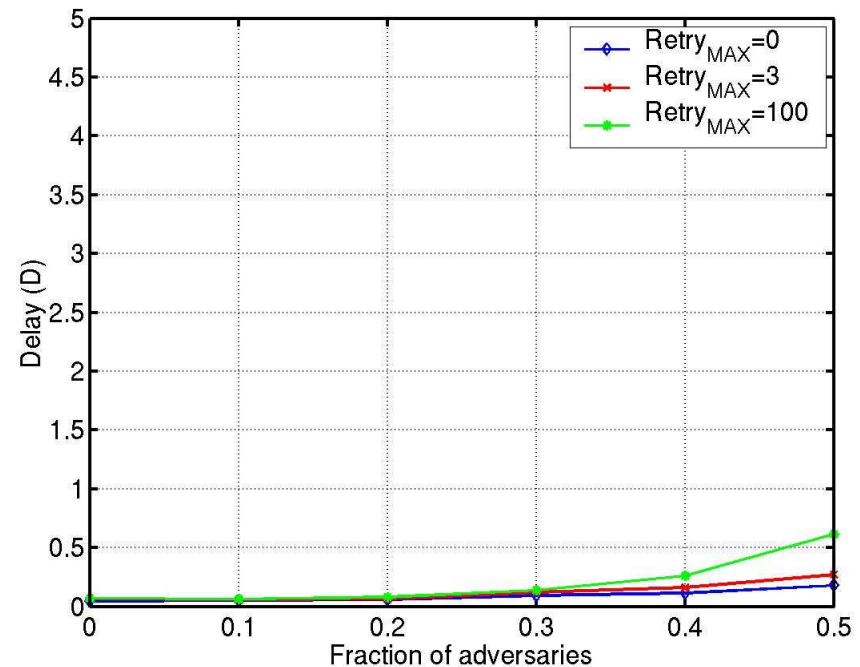
[P. Papadimitratos and Z.J. Haas, "Securing Mobile Ad Hoc Networks," *The Handbook of Ad Hoc Wireless Networks*, CRC Press 2003]

- *SMT* requires a single end-to-end security association (no need for intermediate security assn.)
- *SMT* secures the communication, providing reliable and low-delay data delivery
- *SMT* shows resilience to a significant fraction of Byzantine adversaries
- *SMT* generates only moderate excessive network overhead

# SMT Performance Evaluation (I)



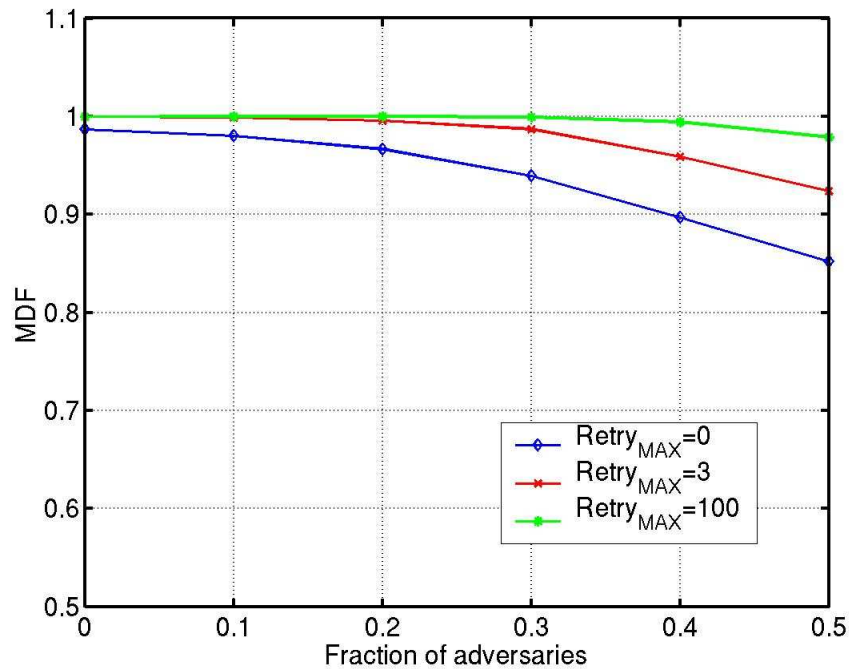
Message Delivery Fraction



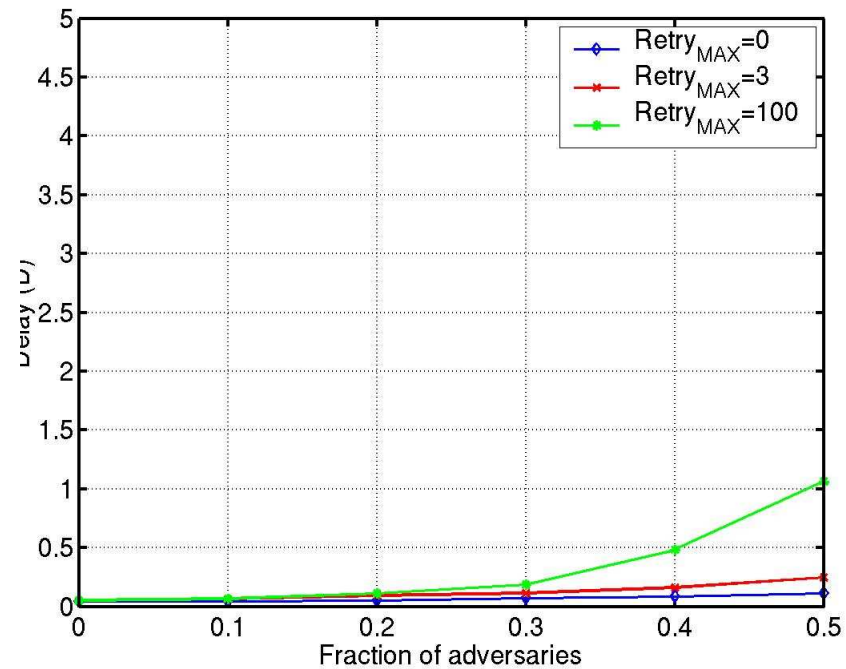
Message Delay

## SMT-LS: SMT with a Link State Protocol

## SMT Performance Evaluation (II)



Message Delivery Fraction



Message Delay

### SMT-RRD: SMT with Secure Routing Protocol

# Analyzing DC: Understanding Path Lifetime in MANET

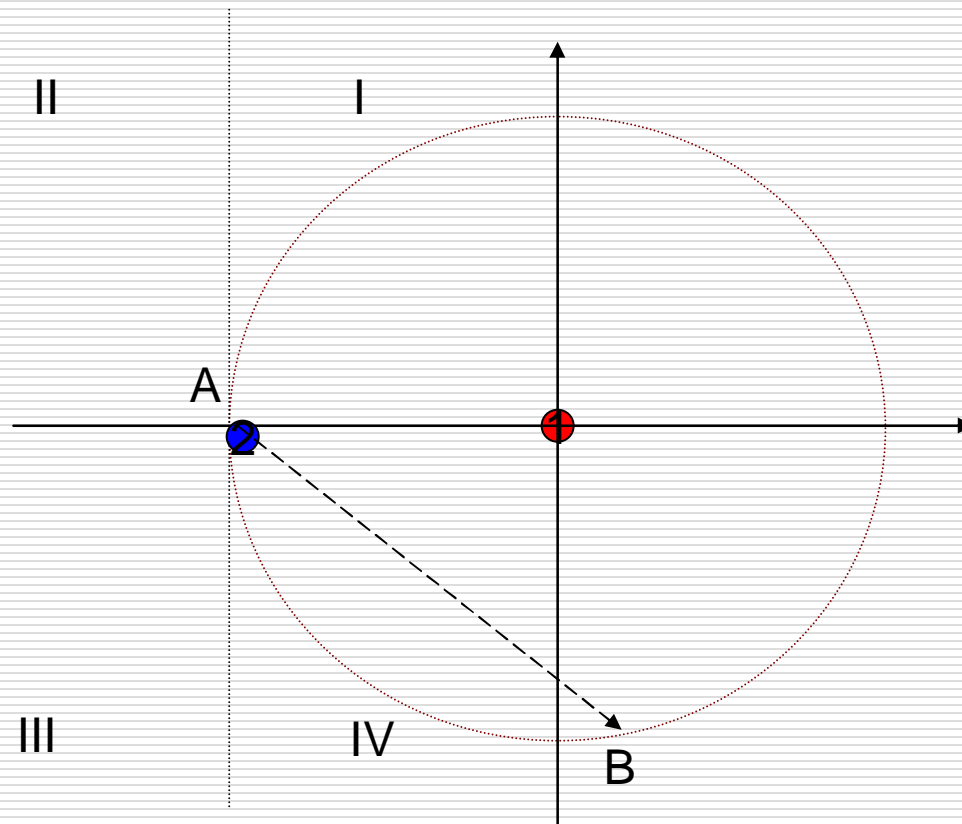
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- The first step in analyzing DC is the study of path lifetime
- Lifetime  $Y$  of a  $L$ -hop path equals to the lifetime of the shortest-lived of all constituent links  $X_i$  on the path

$$Y = \min(X_1, X_2, \dots, X_L)$$

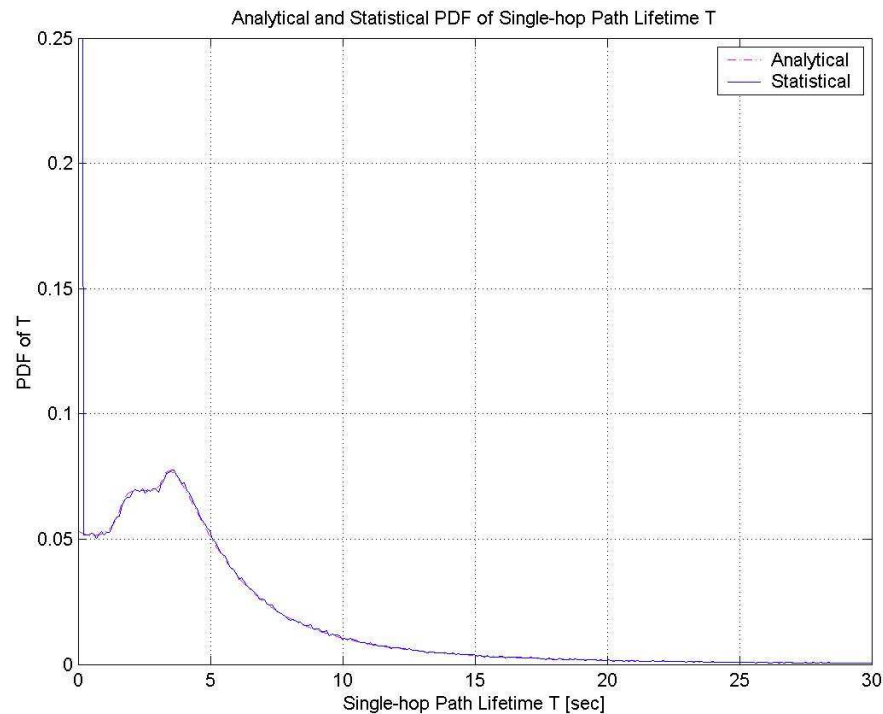
- Difficult to model analytically the lifetime of a (multi-hop) path in the MANET with realistic assumptions
  - Most study of path lifetime done in simulations
- Some observations
  - Nodes on a path exhibit correlation that compromises path lifetime
  - This correlation is proportional to the Euclidian distance between two neighboring nodes
  - Greater Euclidian distance skews PDF towards  $t=0$  [sec]

# Analyzing Path Lifetime: the two-node link model



**Link Lifetime: the duration of time for the blue node to traverse from Point A to Point B, within the transmission range of the red node**

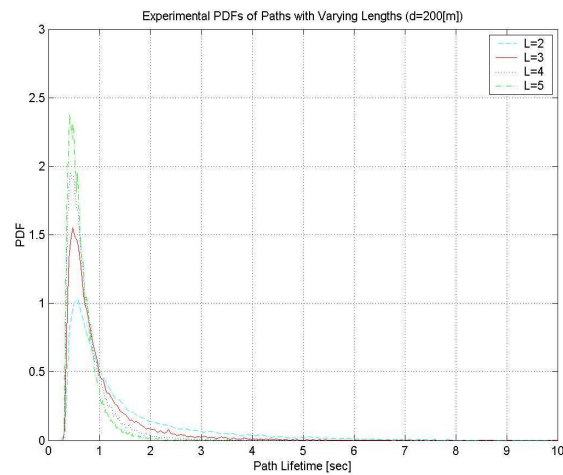
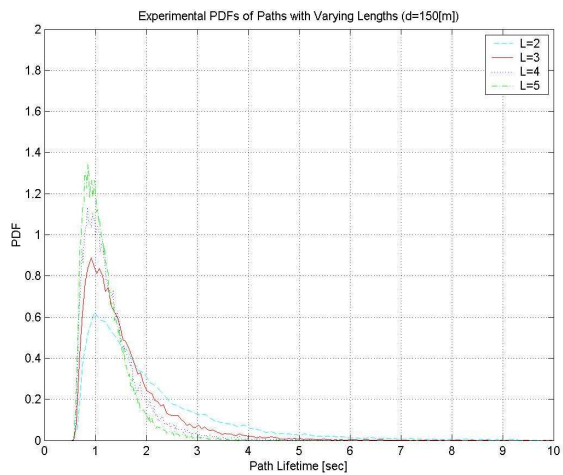
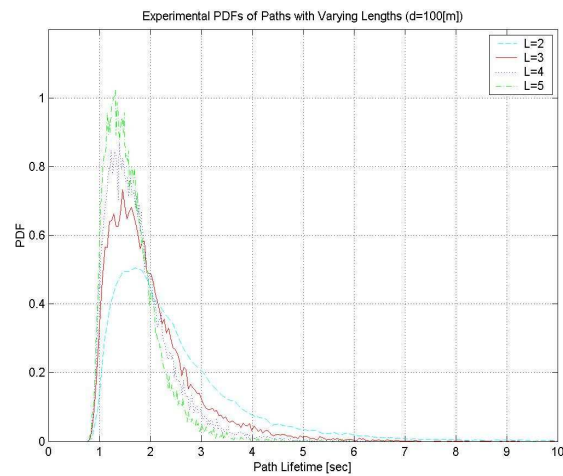
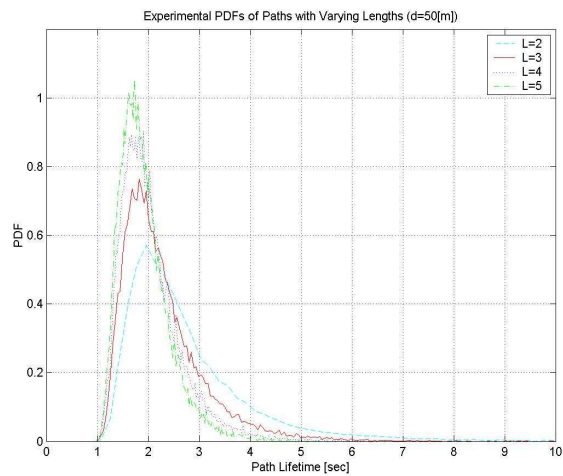
# Analyzing Path Lifetime: The *pdf* of single-hop path lifetime



## Analytical and statistical PDF of a single-hop path lifetime

- Assumed co-dependence between direction and magnitude of a node velocity
- Analytical *pdf* is in a closed-form expression

# Statistical *pdf* of Multi-hop Path Lifetime with Respect to Distance between Nodes



Note: hops of the path assumed to be equidistant

## Summary

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- *Multipath Routing (MR)*, together with *Diversity Coding (DC)*, creates a **cross-layers mechanism** that allow to support numerous Quality-of-Service features in ad hoc networks.
- In particular, the *MR/DC* scheme allows to support highly reliable communication environment, suitable for interactive real-time communication across a highly unreliable ad hoc network.
- As another example, the *MR/DC* scheme can support secure communication environment.
- For maximum benefit, the *MR/DC* scheme requires cross-layers interaction between the MAC layer, the networking layer, the transport layer, and the application layer.
- We are currently evaluating the model of the *Multipath Routing/Diversity Coding* scheme, both analytically and through simulations.

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