Analytical Model for Update Optimization For Proactive Routing Protocols in MANETs

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Sponsor:

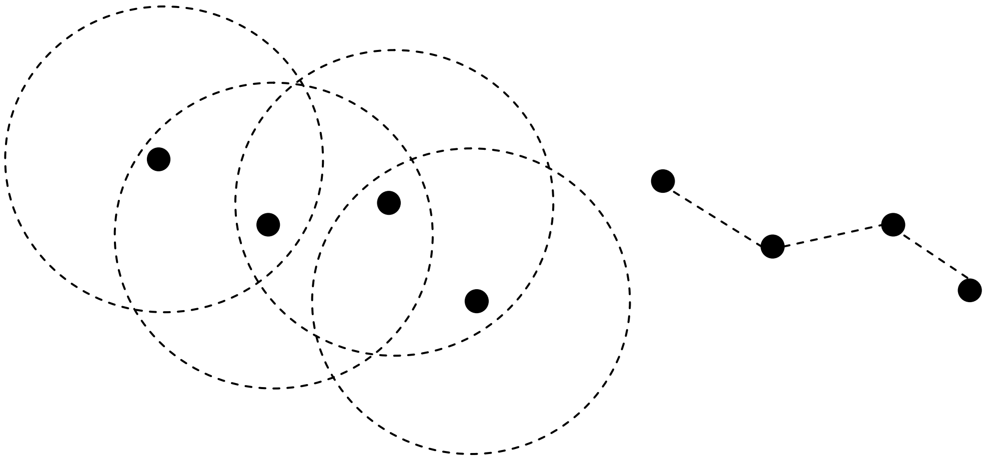
Contributions

- Classification of Proactive Protocols based on Maintenance Operations.
- Analytical Model determining optimum beacon and route update intervals.
- Analysis applied to all classes of protocols.
- Creating the potential of upgrading proactive protocols to enhanced-quality service.

Mobile Ad hoc Networks (MANETs)

Network Model

- mobile nodes (PDAs, laptops etc.)
- multi-hop routes between nodes
- no fixed infrastructure



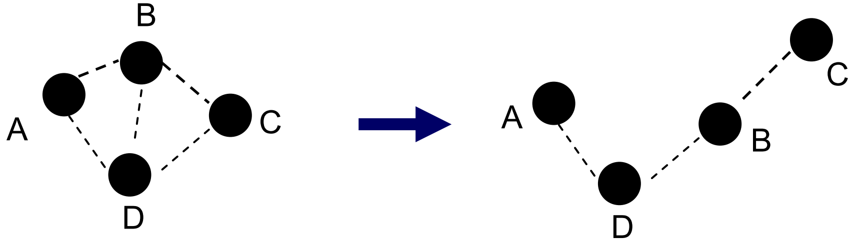
Multi-hop routes generated among nodes

Applications

- Battlefield operations
- Disaster Relief
- Personal area networking

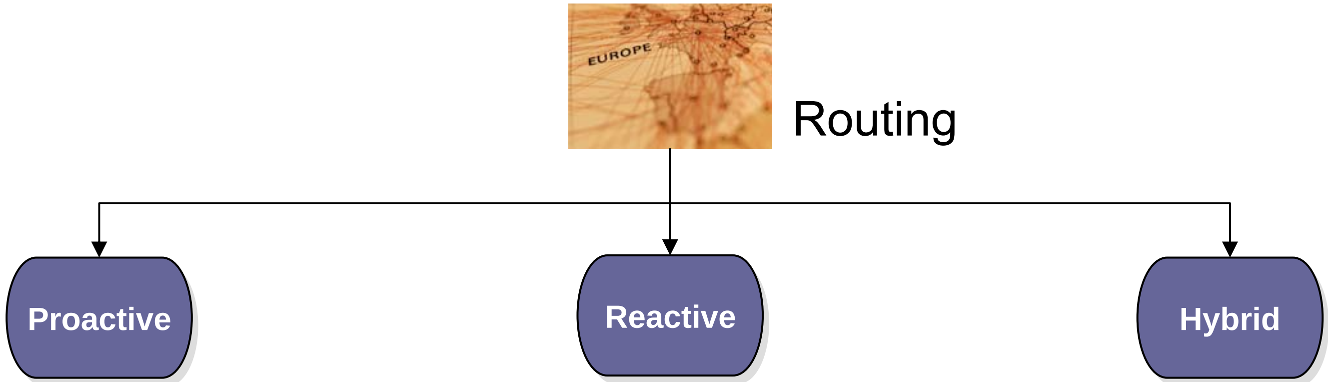
Network Characteristics

- Dynamic Topology
- Constrained resources
  - Limited battery capacity



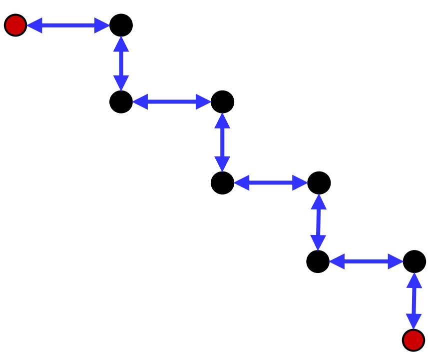
Links formed and broken with mobility

Routing in MANETs



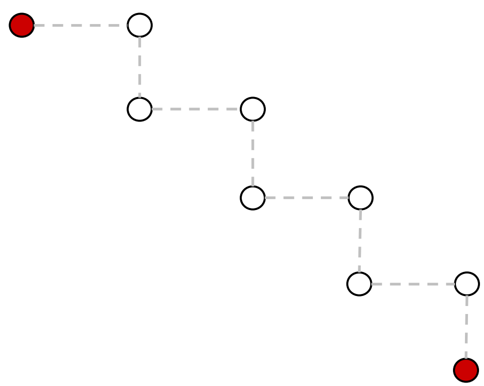
Proactive

- ***Periodically maintains*** routes between every mobile node pair.
- Predefined routes available
- Low latency
- Low scalability.



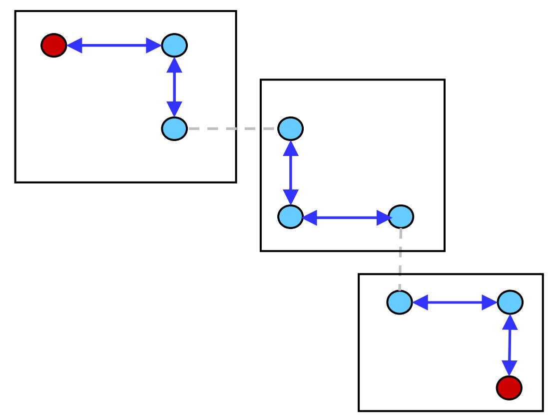
Reactive

- Routes ***NOT*** maintained.
- Route established only if data to transmit.
- High Scalability.
- No pre-defined route.
- High Latency.



Hybrid

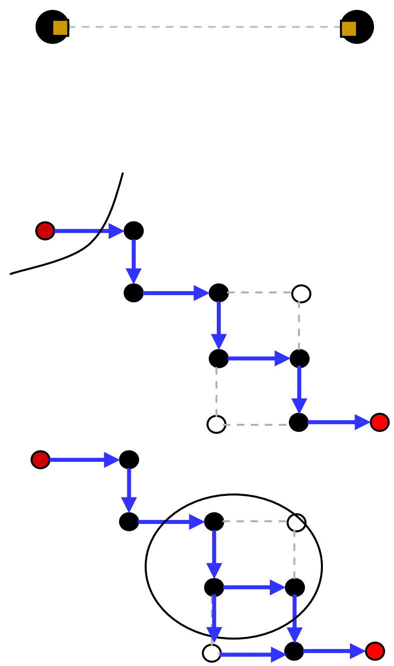
- Network ***divided*** in small zones.
- Intra-region Proactive Routing.
- Reactive Inter-region routing.
- Balances Proactive & Reactive.
- Scalable.
- Latency higher than proactive.



Real-time applications such as Disaster Relief and Battle-field operations require Proactive Maintenance of Route.

Proactive Route Maintenance

- Overhead
  - ***Periodic*** beacon messages for link state maintenance.
  - ***Periodic*** route update b'cast.
  - ***Triggered*** route update b'cast with each link change.



Energy Consumption per bit transmitted — Number of Nodes — Beacon Interval

$E \times N \times \lceil \log N \rceil / \beta$

Bits transmitted due to beaconing per unit time — Average size of beacon msg

$E \times N^2 \times \lceil \log N \rceil / \varphi$

Bit transmitted per unit time for periodic broadcast — Route Broadcast Interval

$E \times N^2 \times \lceil \log N \rceil$

for each triggered update

High Energy Overhead in Maintenance Operations ➡ Low Scalability ➡ Reduces Applicability

Find optimum β & φ to minimize energy overhead.

Periodic Broadcast based on Link Dynamics (LD)

- Determines optimum φ [Samar '06].
  - periodic b'cast of route update only when link changes.
  - Optimum β and scalability needs to be considered.

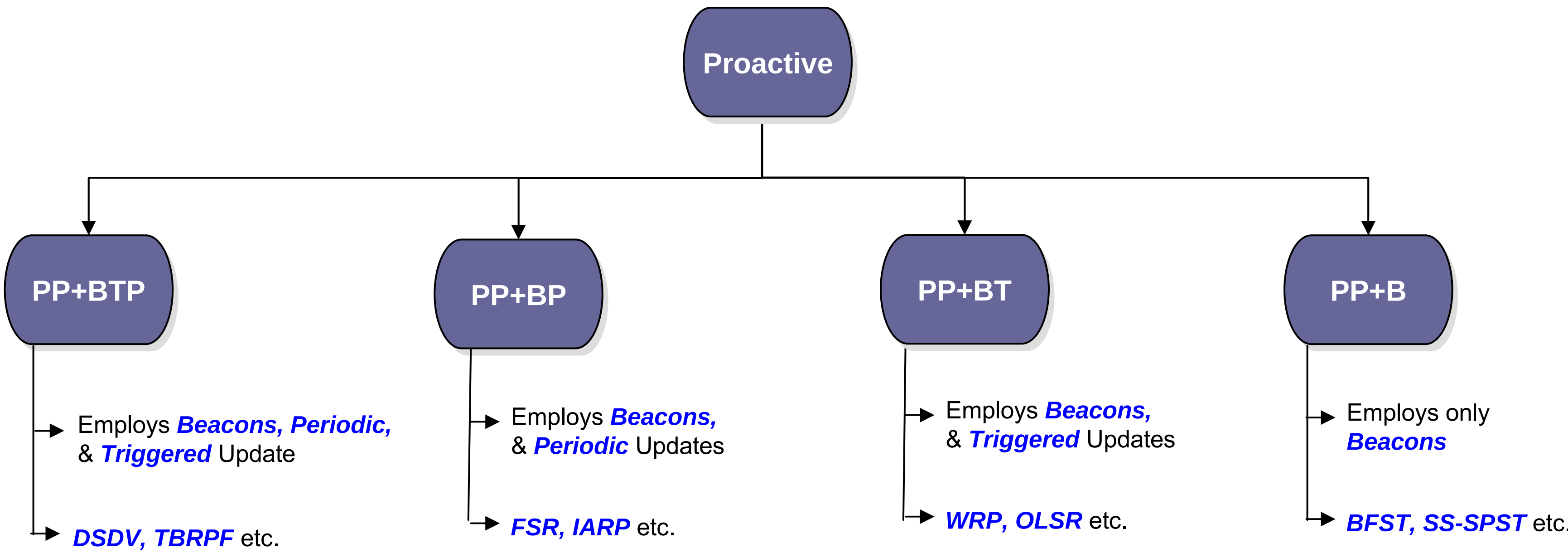
- Extensions and further issues needed to be considered
  - Traffic – route maintenance *can be reduced* for low traffic.
  - Reliability Requirements
    - Measured in terms of Packet Delivery Ratio (PDR).
      - PDR = Total Number of Delivered Packets / Total Packets Transmitted
    - Route maintenance *can be reduced* for low PDR.

Goals

- Balance *Proactivity*, based on application parameters (i.e. PDR and end-to-end latency).
- Minimize Energy Overhead.
- Maintain Application Required Reliability.
- Improve Scalability of Proactive Protocols.

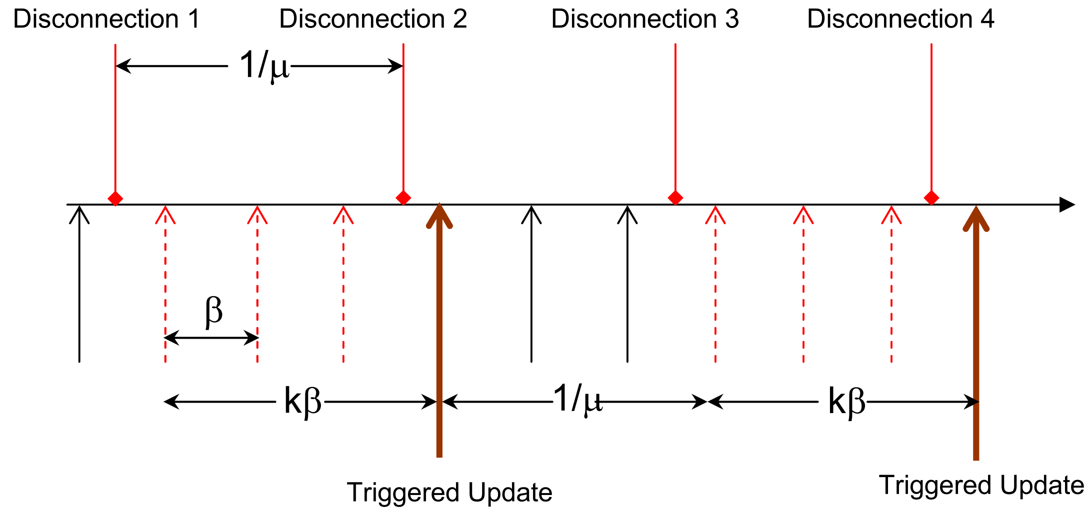
- Provide an application-aware service add-on to routing

Proactive Protocol Classification



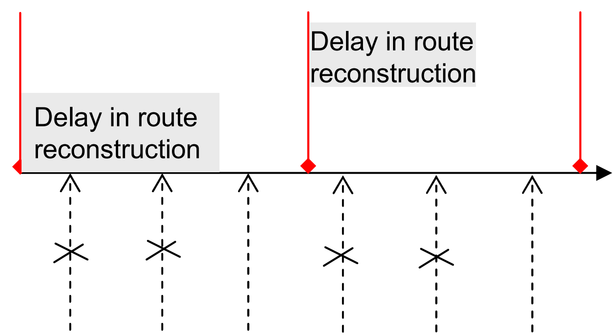
Assumptions & System Model

- Network Parameters
  - Link changes Poisson distributed (avg. rate = μ) [Samar '06].
  - Avg. rate of triggered update depends on μ and β.
    - determines overhead for triggered b'cast.
  - Packet loss due to delay in route reconstruction.
    - Link reliability assumed.
    - No packet re-transmission.



Average interval between consecutive triggered update

- Application Parameters
  - Bulk Poisson Traffic Model (avg. rate = λ).
    - Voice/Audio/Video/Media Traffic.
  - PDR requirement (Γ) known.



Packet loss dependent on route reconstruction delay

PROBLEM: Determine optimum $\beta = f(\mu, N, \lambda, \Gamma)$ & $\varphi = g(\mu, N, \lambda, \Gamma)$.

Analytical Model

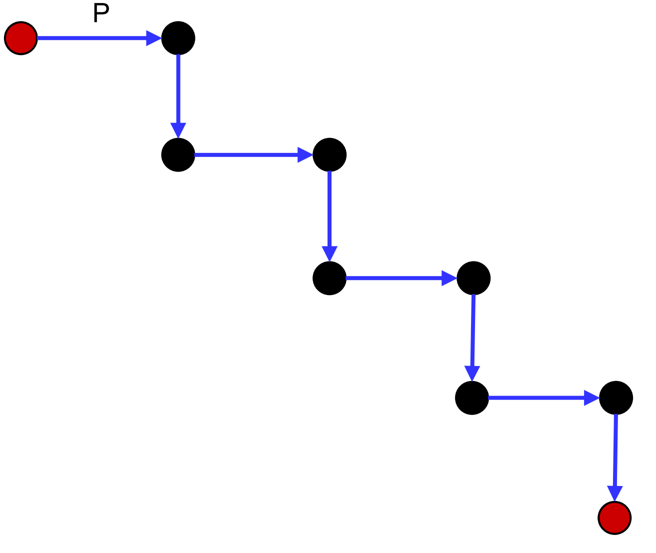
- Objective Function
- Constraints
- Optimization

Objective Function: Overhead Energy

	Cost of Beacons	Cost of Triggered B'cast	Cost of Periodic B'cast
PP+BTP	$E_{Ov} = \frac{N}{\beta}\lceil logN \rceil E$	+ $\frac{DN^2\mu}{1+\mu k\beta}\lceil logN \rceil E$	+ $\frac{N^2}{\varphi}\lceil logN \rceil E$
PP+BP	$E_{Ov} = \frac{N}{\beta}\lceil logN \rceil E$		+ $\frac{N^2}{\varphi}\lceil logN \rceil E$
PP+BT	$E_{Ov} = \frac{N}{\beta}\lceil logN \rceil E$	+ $\frac{DN^2\mu}{1+\mu k\beta}\lceil logN \rceil E$	
PP+B	$E_{Ov} = \frac{N}{\beta}\lceil logN \rceil E$		

Constraints

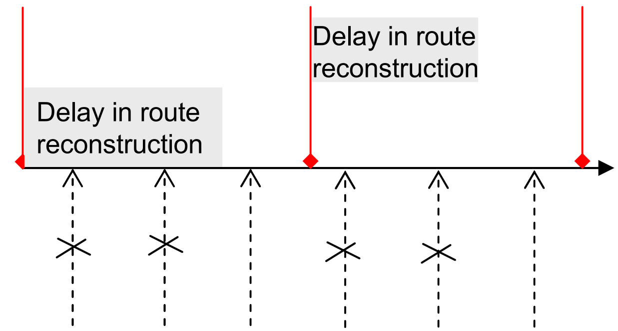
- PDR Constraint
  - P = Probability of packet loss due to each link failure.
  - PDR = $(1 - P)^D$.
  - **$(1 - P)^D >= \Gamma$.**
  - Find P = function of μ, λ, β, φ.



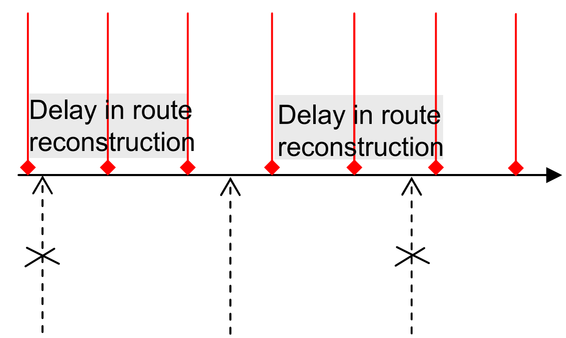
- Bandwidth/Capacity Constraint
  - Control Traffic.
  - Data Traffic.

Probability of Packet Loss (P)

- CASE I: Link disconnection rate greater than traffic generation rate
  - Route-reconstruction delay MUST be less than consecutive link disconnections in the route.
  - $P_1 = \mu \times$ route-reconstruction delay



- CASE II: Link disconnection rate less than traffic generation rate
  - Route-reconstruction delay MUST be less than average interval between consecutive packets.
  - $P_2 = \lambda \times$ route-reconstruction delay



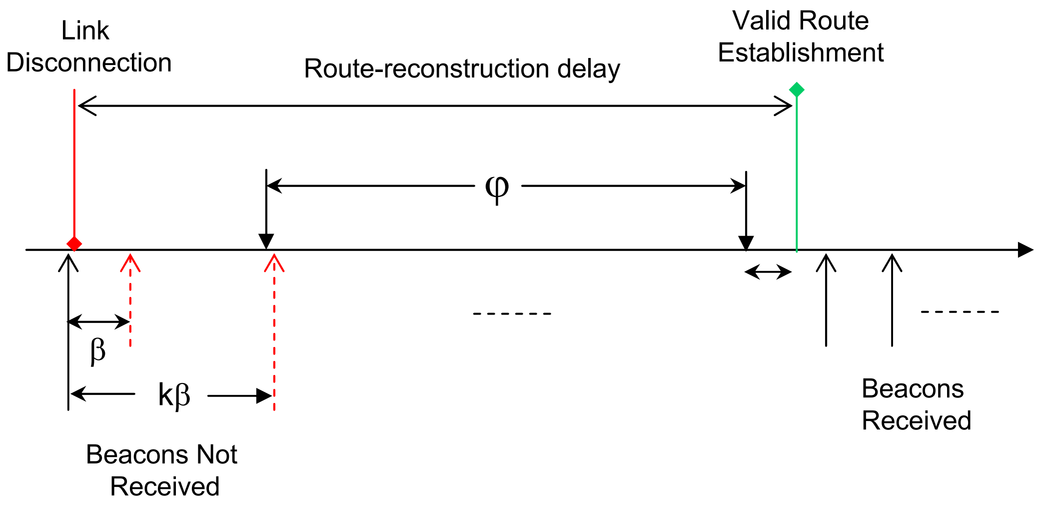
$$P = P_1 \times \text{prob of CASE I} + P_2 \times \text{prob of CASE II}$$

$$= \Omega \times \text{route-reconstruction delay}$$

PDR Constraint: route-reconstruction delay <= $[1 - \Gamma^{1/D}] / \Omega$

Optimization

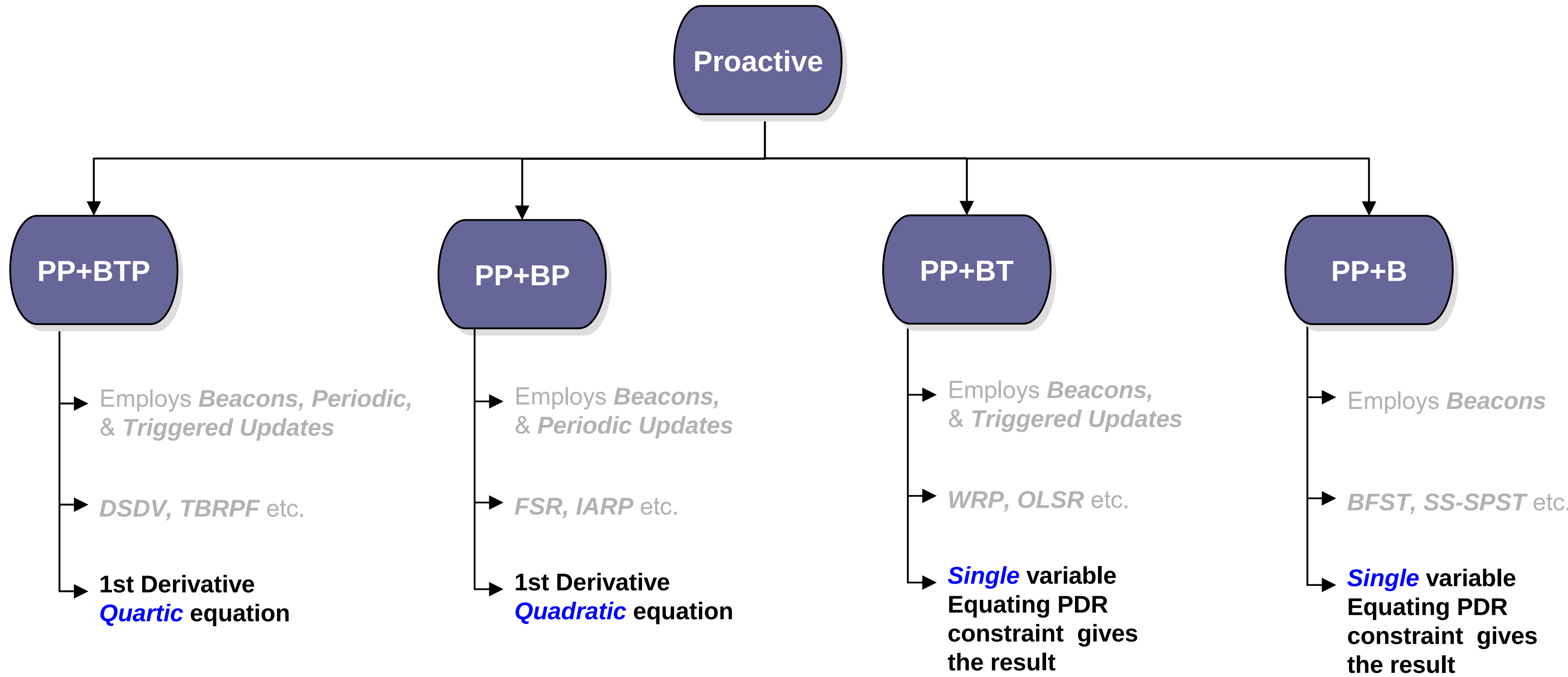
- Step 1: route-reconstruction delay in terms of β and φ.
- Step 2: take the equality of the PDR constraint
  - optimum value at the boundary.
  - one variable represented in terms of other.
  - objective re-written as a convex function of one variable.



Worst case route-reconstruction delay = kβ + φ + end-to-end broadcast delay.

- Step3: non-linear optimization of the objective
  - equate first order derivative to 0.
  - the resulting equation solved
  - second order derivative checked for positive slope.

Optimizations for different Proactive Protocols

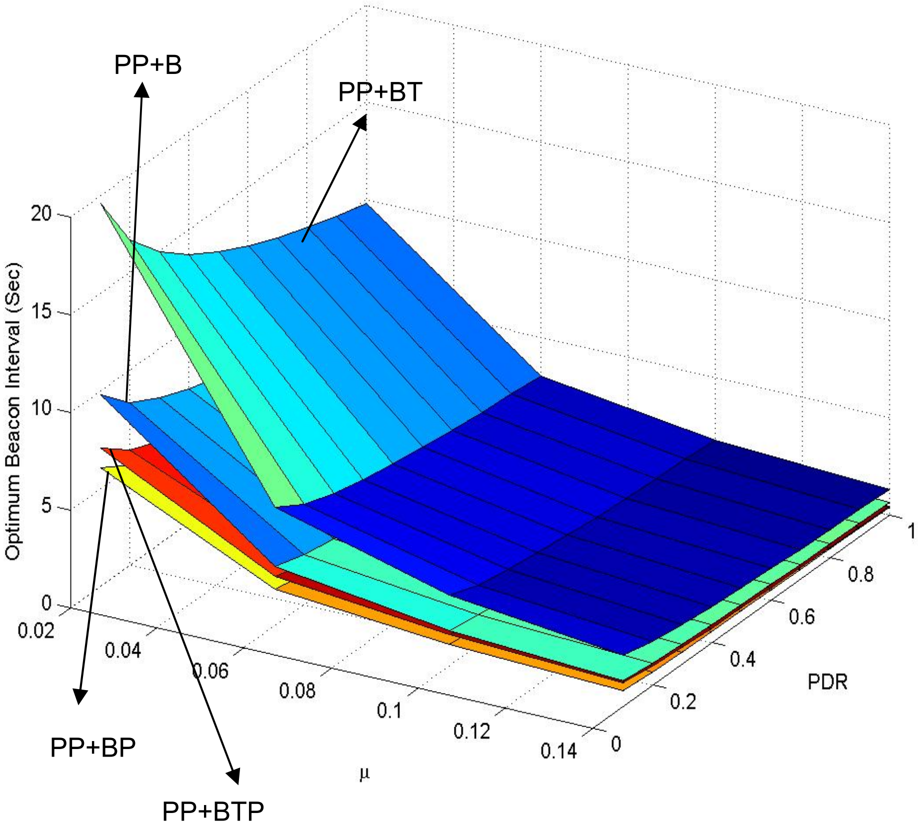


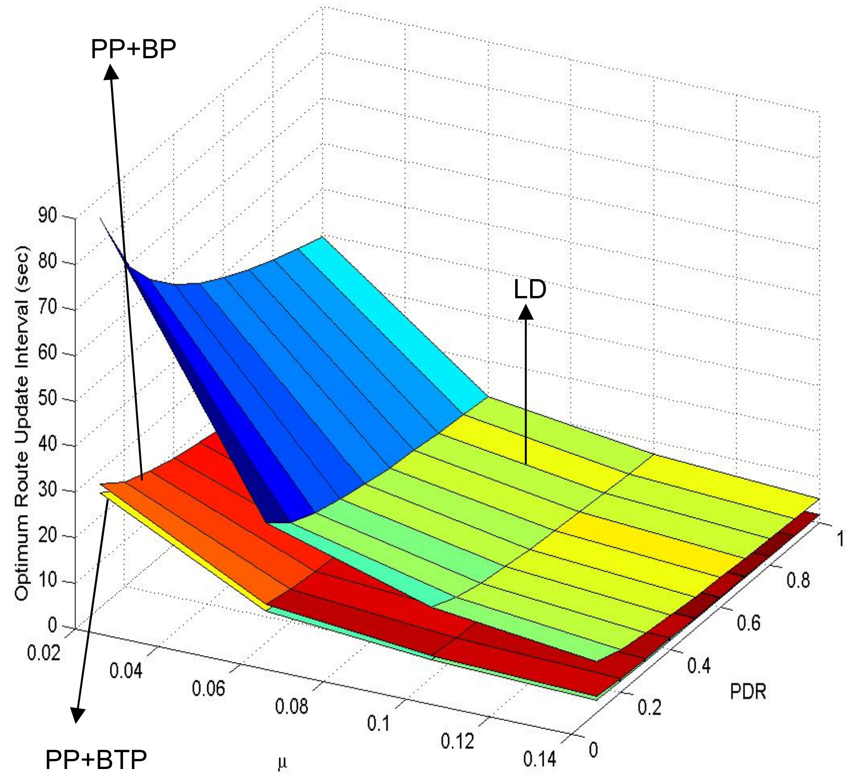
$$\infty > \varphi_{opt} \ge \left(\frac{1-\Gamma^{\frac{1}{D}}}{\lambda\alpha+\Lambda}\right)\left(1+N\sqrt{\frac{k+N^3}{N}}\right)^{-1} \qquad \varphi_{opt} d_{rec} = \frac{1-\Gamma^{\frac{1}{D}}}{\Omega\left(N+\sqrt{k}\right)}$$

$$\infty > \beta_{opt} \ge \frac{\frac{1-\Gamma^{\frac{1}{D}}}{\lambda\alpha+\Lambda}}{k}\left(1+\frac{N\sqrt{k}}{\sqrt{k+N^3}}\right)^{-1} \qquad \beta_{opt} d_{rec} = \frac{1-\Gamma^{\frac{1}{D}}}{\Omega\sqrt{k}\left(N+\sqrt{k}\right)}$$

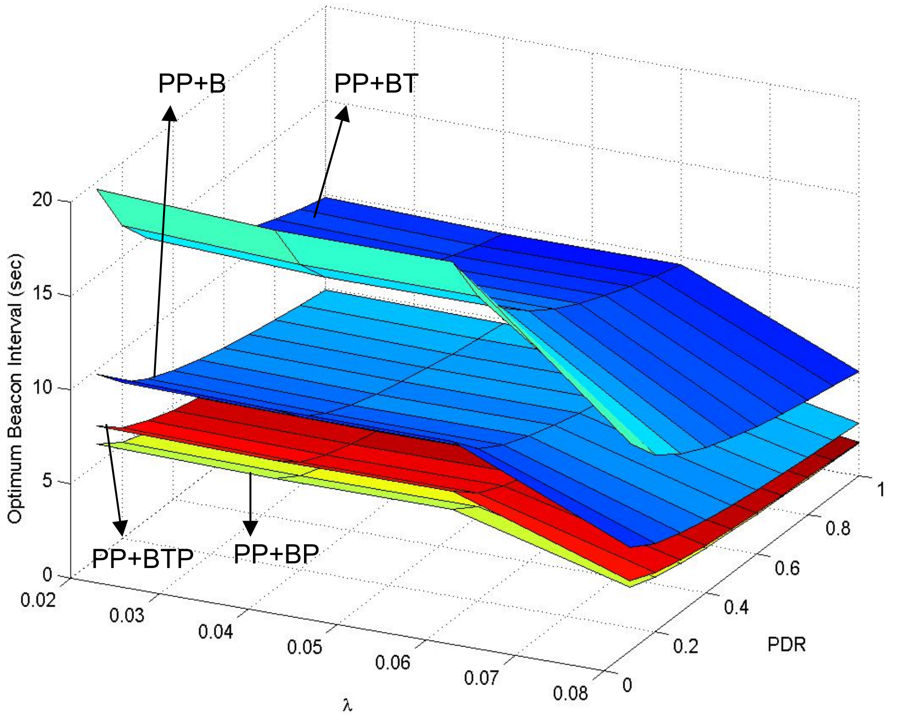
$$\beta_{opt} = \frac{1-\Gamma^{\frac{1}{D}}}{\Omega k} \qquad \beta_{opt} = \frac{1-\Gamma^{\frac{1}{D}}}{\left(k+\sum_{i=0}^{D} c^i\right)\Omega}$$

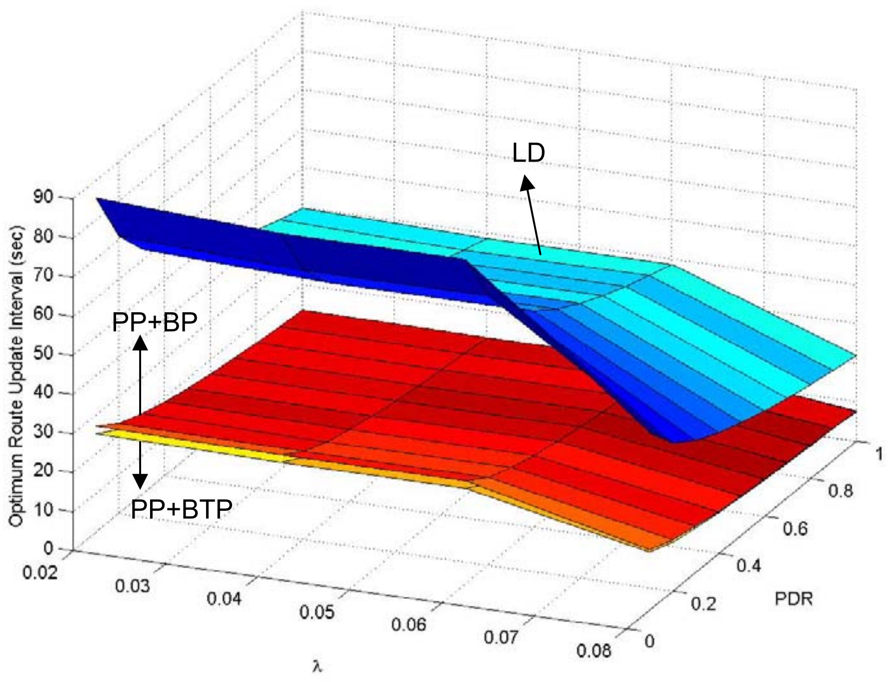
Optimum Periods w.r.t. link change



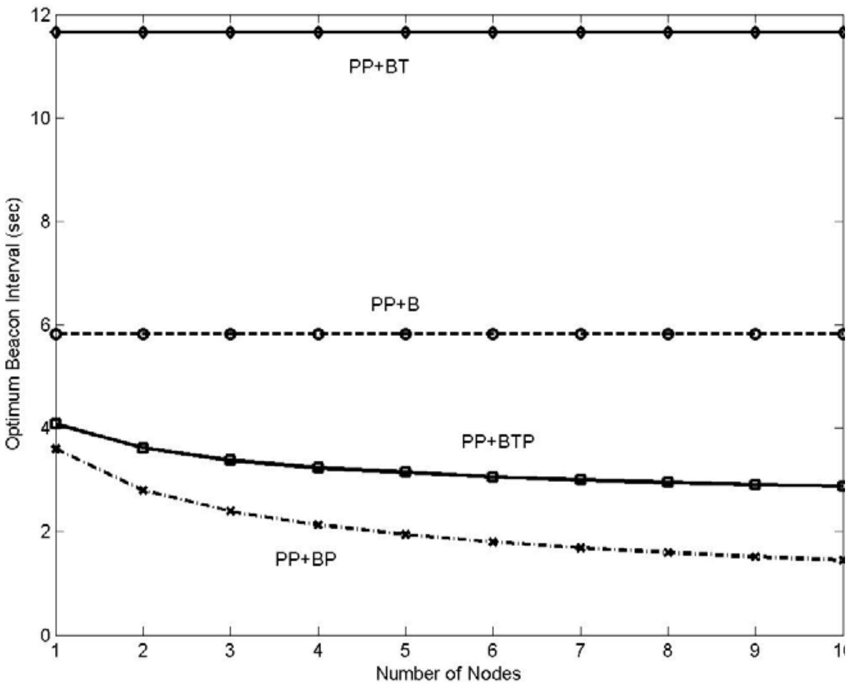


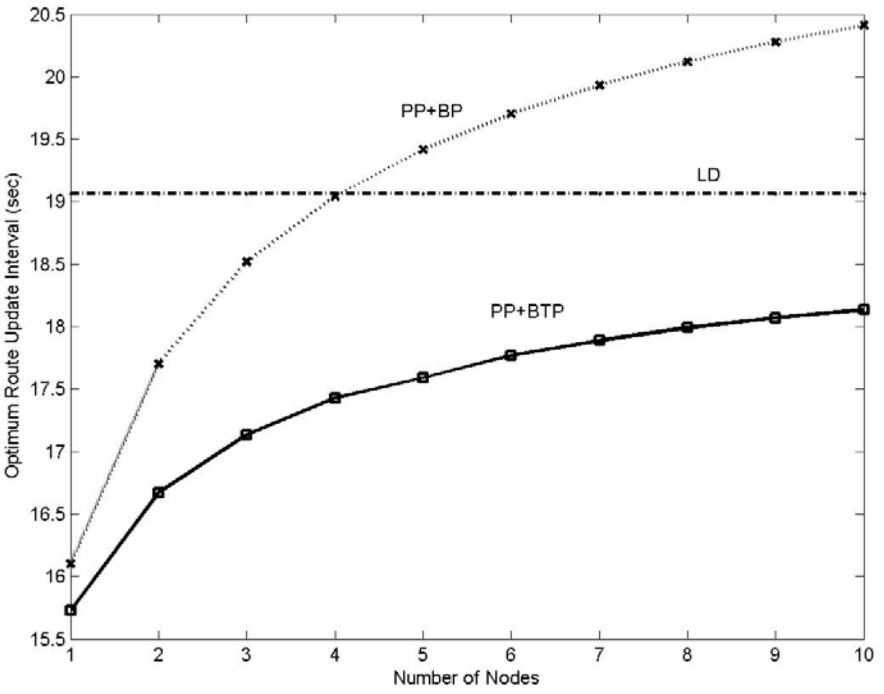
Optimum Periods w.r.t. traffic intensity





Optimum Periods w.r.t. Network Size





- Decrease Periodic Update Frequency
  - Decreases broadcast.
  - Increases Scalability.
- Increase beacon frequency to meet PDR Constraint.

Conclusions

- Novel analytical model developed to find optimum periods of maintenance operations in Proactive Routing Protocols for MANETs.

- Minimizes overhead energy.
- Maintains reliability
- Can be used to upgrade pro-active routing protocols to an enhanced-quality routing service.

- Summary of results
  - Improves scalability.
  - Reduces wastage for low traffic & mobility.

- Work in progress
  - Application of the model in the proactive protocols

References

- P. Samar, and S. B. Wicker, **Link Dynamics and Protocol Design in a Multihop Mobile Environment**, *In IEEE Transaction of Mobile Computing (TMC)*, Sept. 2006.
- Q. Zhao, and L. Tong, **Energy Efciency of Large-Scale Wireless Networks: Proactive Versus Reactive Networking,** *In IEEE Journal on Selected Areas in Communications*, Vol. 23, No. 5, May, 2005.
- T. Mukherjee, G. Sridharan, S. K. S. Gupta, **Energy-Aware Self-Stabilization in Mobile Ad Hoc Networks: A Multicasting Case Study**, 21st IEEE Int'l Parallel and Distributed Processing Symposium (IPDPS), Long Beach, California, 26-30th March 2007.
- T. Clausen, and P. Jacquet, **Optimized Link State Routing (OLSR) Protocol**, *IETF MANET*, RFC 3626, Oct, 2003.
- E. Royer and C. Toh, **A Review of Current Routing Protocols for Ad-Hoc Mobile Wireless Networks**, *In IEEE Personal Communications.*, Apr. 1999.
- C. Perkins, and P. Bhagwat, **Highly Dynamic Destination Sequenced Distance-Vector Routing (DSDV) for Mobile Computers**, *In Proc. ACM SIGCOMM Conf.*, Oct. 1994.
- G. Pei, M. Gerla, and T. W. Chen, **Fisheye State Routing: A Routing Scheme for Ad Hoc Wireless Networks,** *In Proc. International Conf. Comm.*, 2000.
- I. D. Aron, and S. K. S. Gupta, **On The Scalability Of On-Demand Routing Protocols For Mobile Ad Hoc Networks: An Analytical Study**, *In Journal of Interconnection Networks*, 2001.
- Z. J. Haas, M. R. Pearlman, and P. Samar, **The Intra-zone Routing Protocol (IARP) for Ad Hoc Networks**, *IETF MANET*, Internet Draft, Jul, 2002.

Questions ??