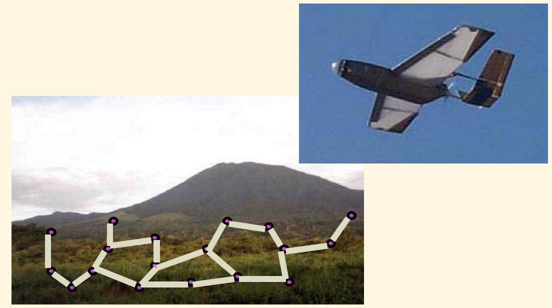

Lifetime-Aware Hierarchical Wireless Sensor Network Architecture with Mobile Overlays

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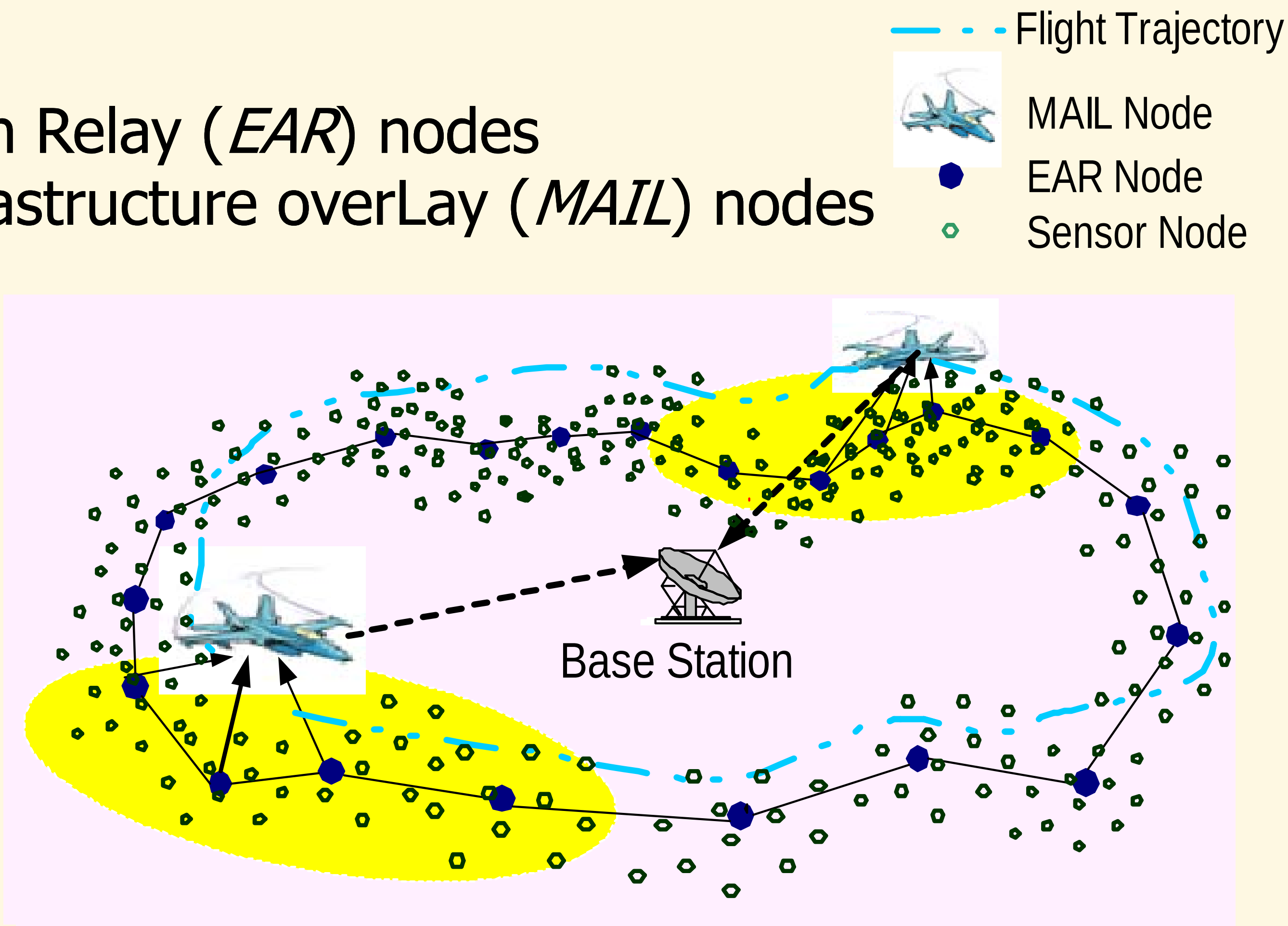
Outline

- Network structure and objectives
- Routing protocol
- System analysis
- Results
- Conclusion

Hierarchical Network Structure

Sensor nodes
Event Aggregation Relay (*EAR*) nodes
Mobile Aerial Infrastructure overLay (*MAIL*) nodes
Base Station

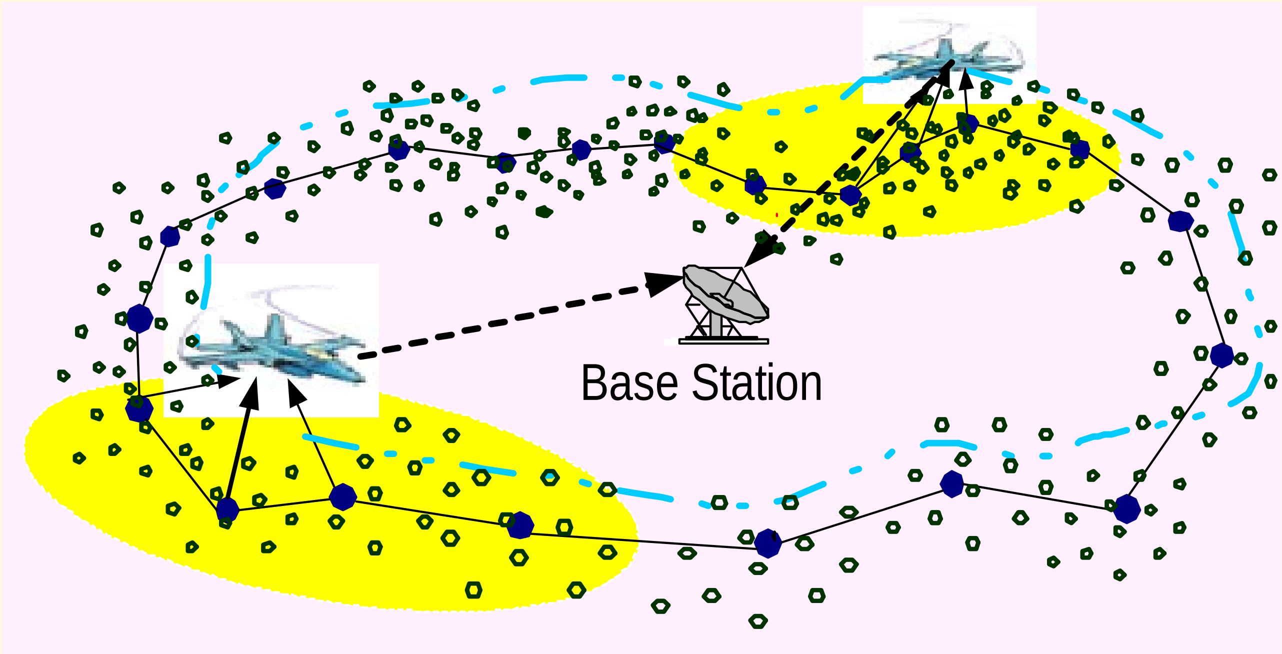
M # of *MAIL* nodes
N # of *EAR* nodes



- Recurrent cycle
- Network Monitoring Lifetime (*MoL*)

Objectives

- Analysis of concurrent controllable mobility and multi-hop routing in a multi-tier network



- Design and Analysis of Mobility-aware routing protocol

Motivation

Lower energy dissipation ⟹ Longer lifetime.

- Energy consumption for wireless transmission:

$$\varepsilon = e_t d^{\beta}$$

d : Distance

e_t : Energy dissipation for transmitting unit of data over unit of distance

β : Path loss exponent

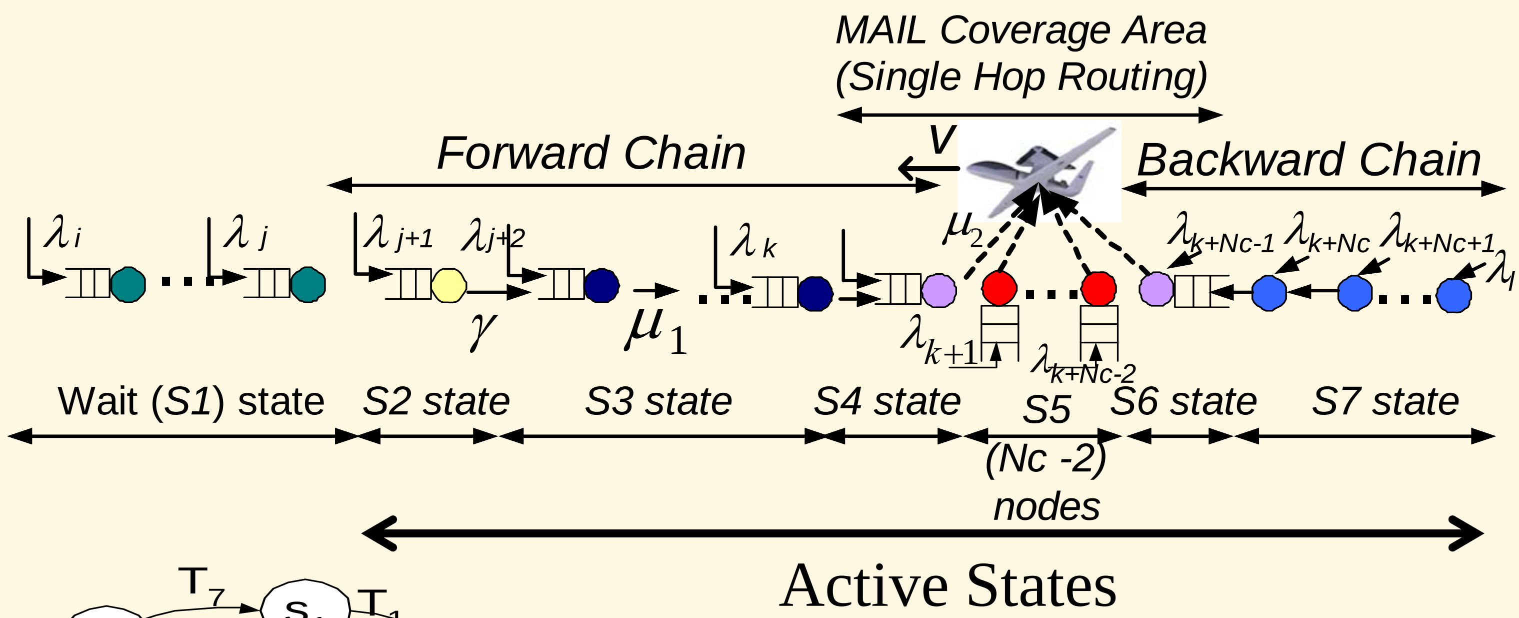
• Hierarchical network structure and multi-hop routing lowers energy dissipation.

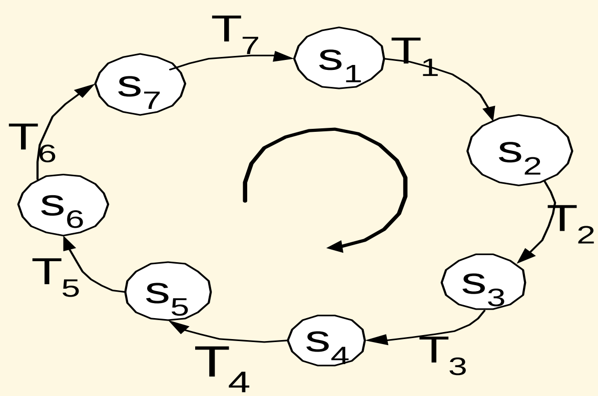
• Mobility brings symmetry in battery depletion

Bounded Hop Count Routing (BHR)

- Multi-hop routing between *EAR* nodes
  - Less network delay and smaller storage size
  - Shorter distance ⇒ Less transmission power
- Dynamic Hop Count *(DHC)* vs. Initial Hop Count *(IHC)*
  - mobility
  - Routing delays
    - transmission, propagation and queueing
- Bounded number of hops
  - route if *hop count <= **H***
  - Storage, delay, and energy trade-off

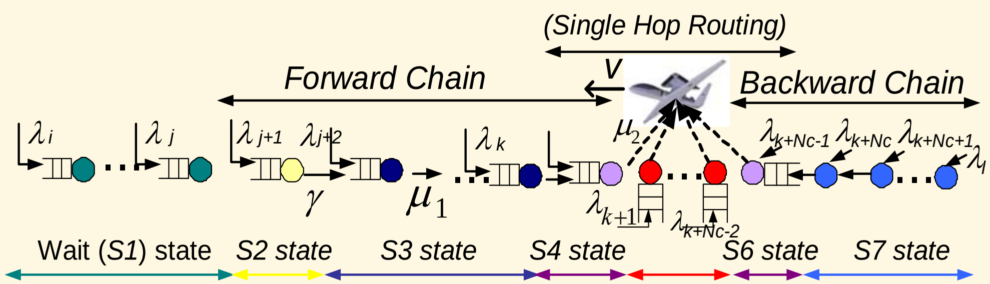
EAR Node Cluster and State Transitions in Each Cycle



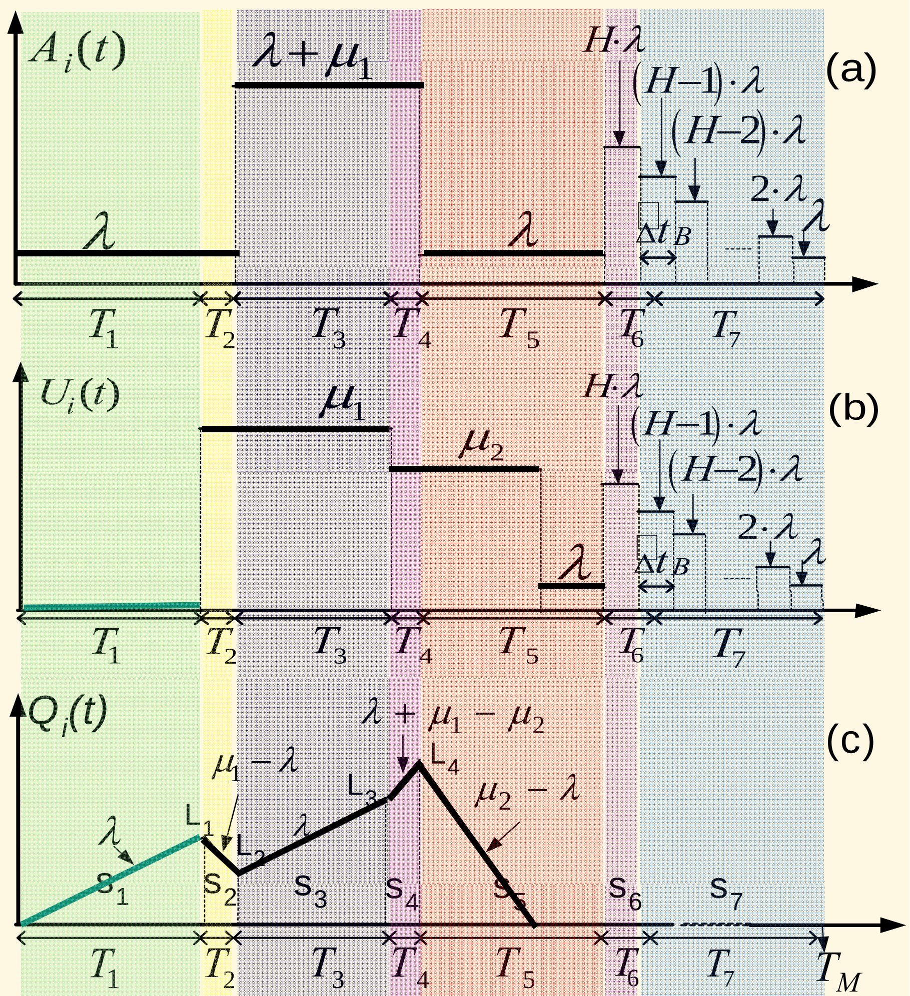


Network of queues with vacation and variable service rate over time

Queuing Analysis of Each *EAR* Node



$H.\lambda < \mu_2 < \mu_1$



(a) Temporal variation of arrival rate for node *i*

(b) Temporal variations of departure rate

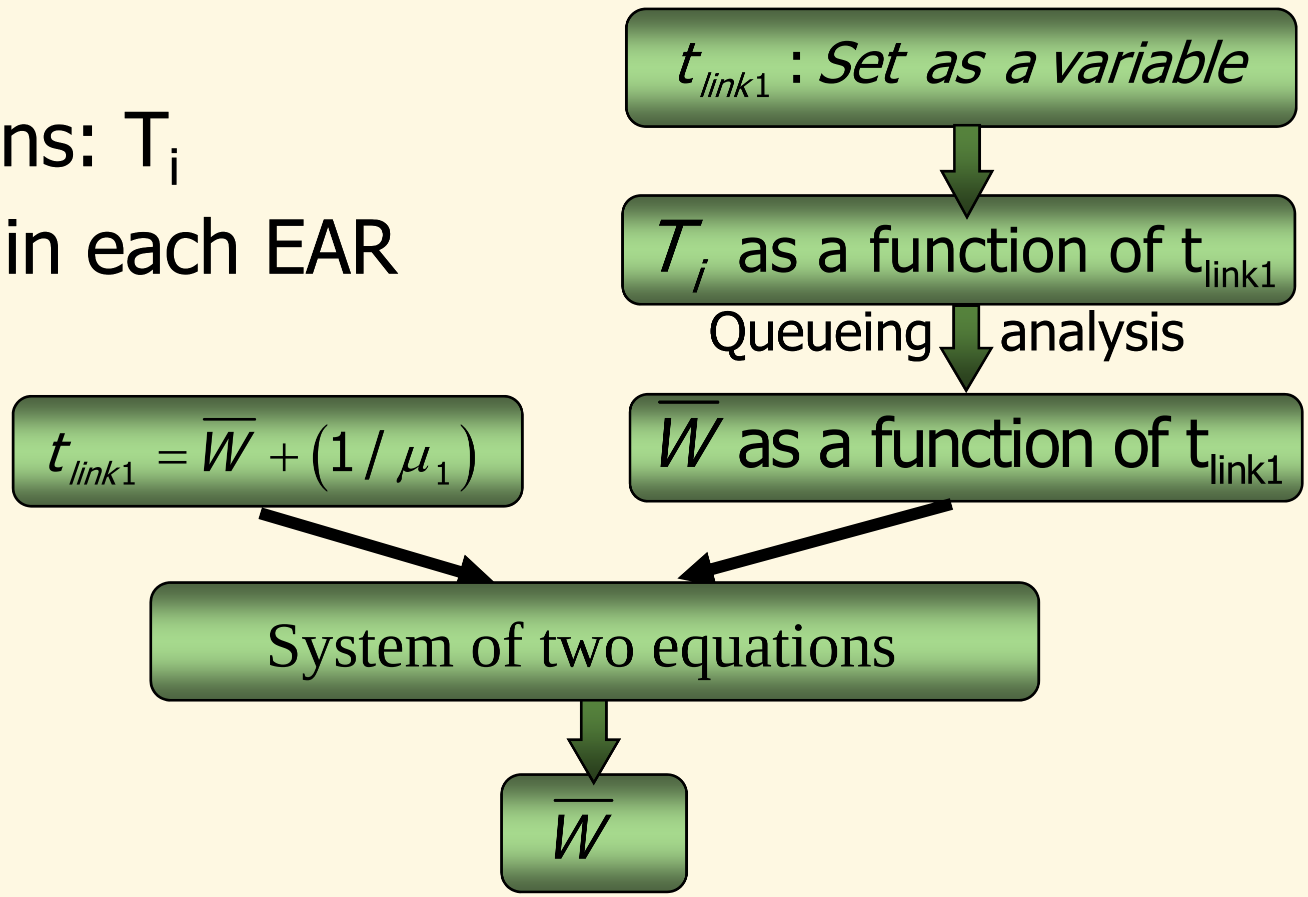
$$\text{For}\left(t > T_1\right) \Rightarrow U_i(t) = \begin{cases} \mu_1 \ or \ \mu_2 & \text{if } Q_i(t) > 0 \\ A_i(t) & \text{if } Q_i(t) = 0 \end{cases},$$

$$\text{otherwise } U_i(t) = 0$$

(c) Temporal Variations of queue size

Waiting Time in Queues

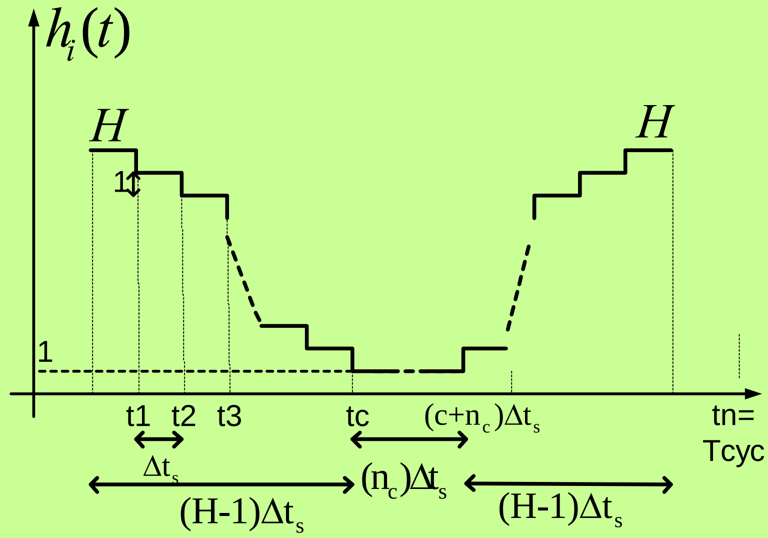
- EAR-to-EAR link delay: t_{link1}
- State durations: T_i
- Avg. waiting in each EAR node: $\overline{W}$



Average Number of Hops for a Packet Transmission

- Hop count for packet delivery from an EAR node to a *MAIL* node
  - Between 1 to H
- Temporal average of *DHC* for a packet delivery

DHC seen by an *EAR* node during one cycle



$$\overline{h} = \frac{1}{T_M}\cdot\left(H\cdot(T_1+T_2)+(T_4+T_5)+(\frac{H+1}{2})\cdot(T_3+T_6)\right)$$

Network Delay

- Average delay for a packet to reach a *MAIL* node, D_{net}

$$D_{net} = \bar{h} \cdot \bar{W} + \frac{(\bar{h} - 1)}{\mu_1} + \frac{1}{\mu_2}$$

Waiting time in queues

EAR-to-*MAIL* communication

EAR-to-*EAR* communications

Network Lifetime

Average energy consumption for a packet delivery:

$$\overline{E} = (\overline{h} - 1) \cdot e_E + e_M$$

e_E: Avg. energy consumption for EAR-to-EAR communication

e_M: Avg. energy consumption for EAR-to-MAIL communication

Average # of packets generated during lifetime of the network: $N \cdot \lambda \cdot T_{net}$

$$\overline{E}.\left(N \cdot \lambda \cdot T_{net}\right) = N \cdot E_0 \Rightarrow T_{net} = \frac{E_0}{\lambda \cdot \overline{\overline{E}}}$$

Optimization Problem

$$\underset{v,H,N_c}{Max}\ T_{sys}$$

$$s.t.\quad D_{net} \le D_{\max},\quad B_p \le B_{\max},\quad c\cdot C_M \le C_{\max}$$

$$T_{sys} = Min(T_{net}, c\cdot T_e)$$

T_e : *MAIL* endurance time $\left(T_e \propto 1/v^3\right)$
T_{net} : Network lifetime
B_p : Peak queue size
C_M: Recharge Cost
c : # of charge occasions

Convex epigraph form:

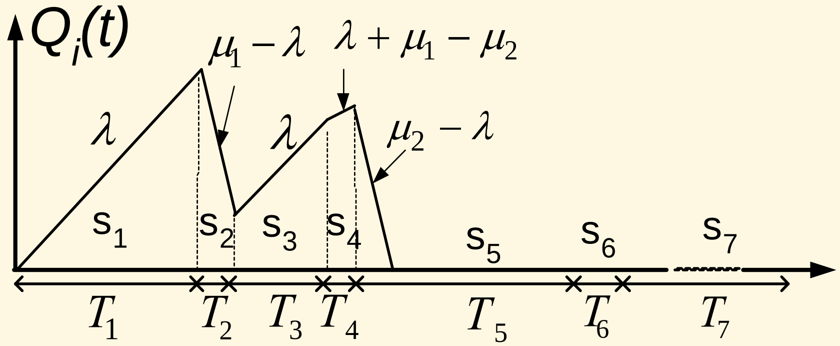
$$f \triangleq 1/T_{sys} \Rightarrow f \ge 1/cT_e,\quad f \ge 1/T_{net}$$

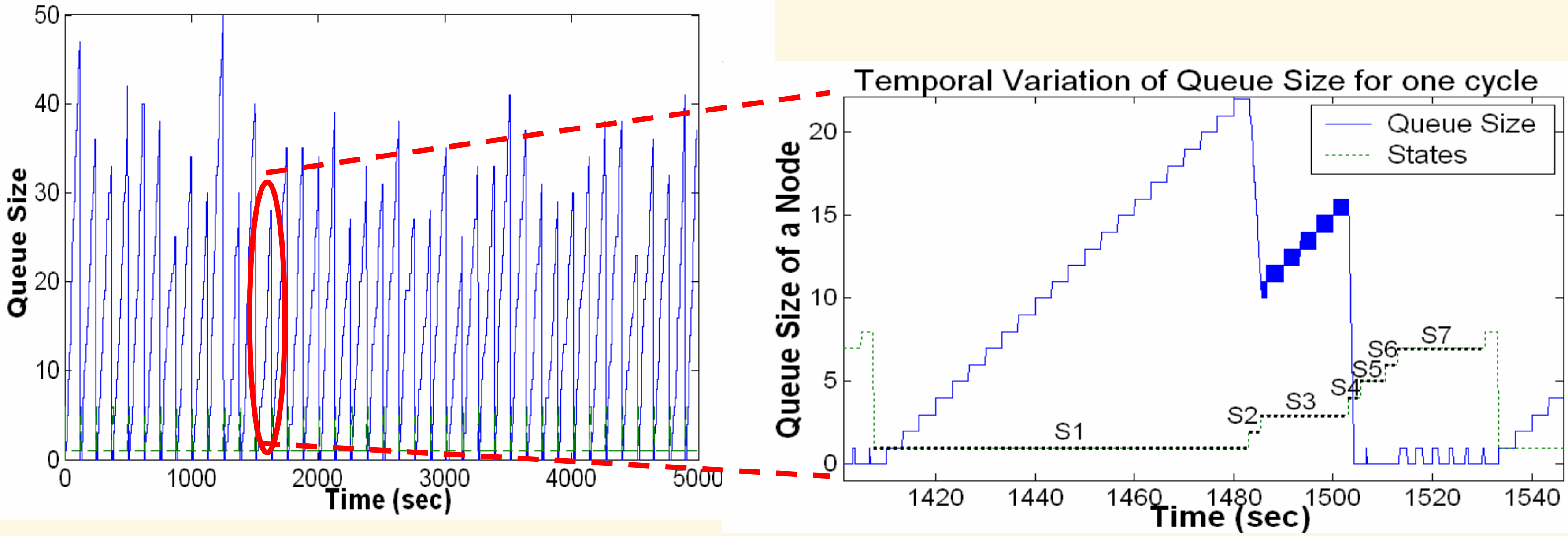
$$\underset{v,H,R_c}{Min}\ f$$
$$s.t.\quad k\lambda\overline{E} - f\cdot E \le 0\quad,\quad \rho\cdot v^3 - f\cdot c\cdot\alpha\cdot E_M \le 0$$
$$and\ D_{net} \le D_{\max},\quad B_p \le B_{\max},\quad c\cdot C_M \le C_{\max}$$

Simulation Results

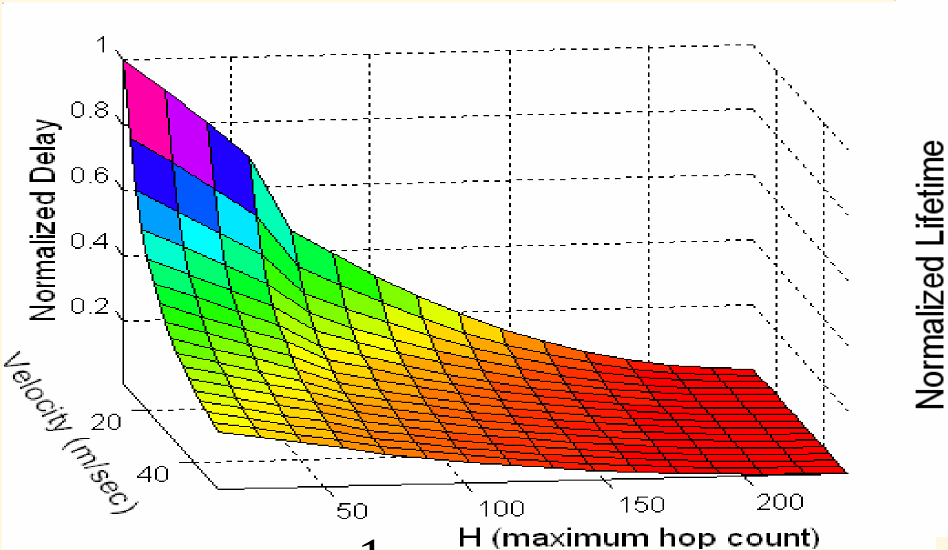
Sample scenario:

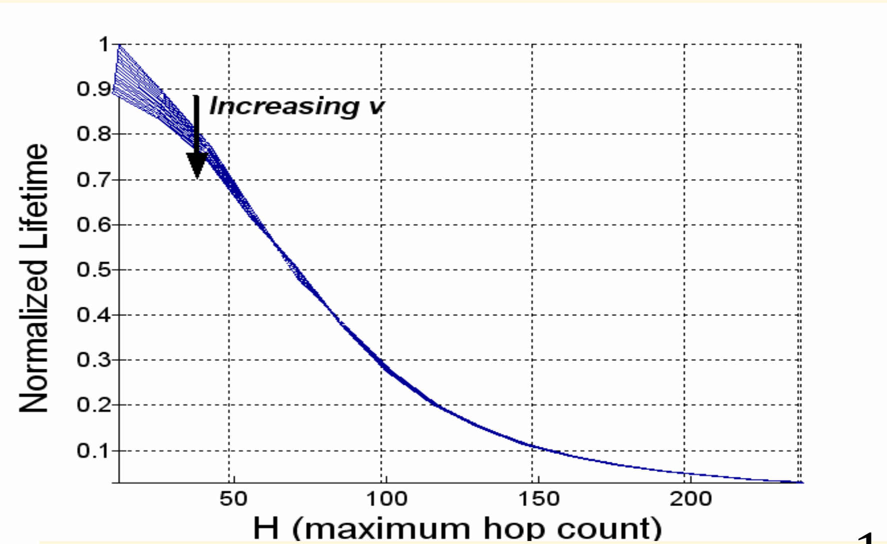
1000 *EAR* nodes
Random distribution
Two *MAIL* nodes
e_t for *EAR-to-EAR:* 0.0013
e_t for *EAR-to-MAIL:* 10 (pJoul/bit/m^2)
λ: 0.3





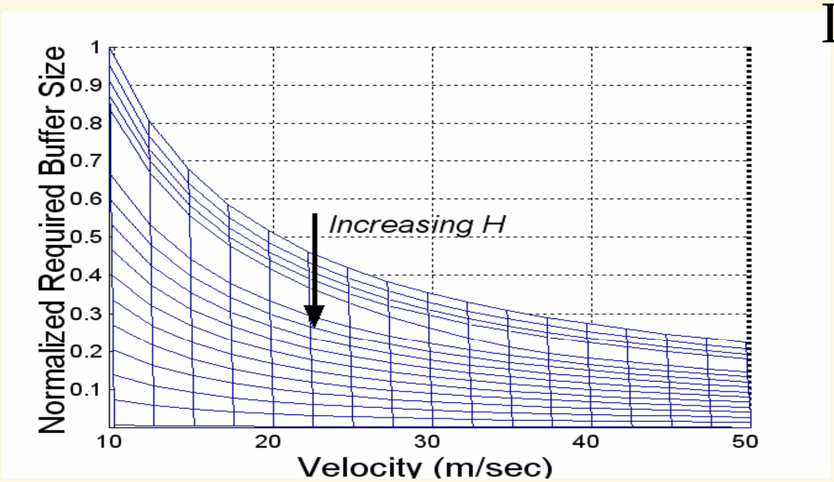
Simulation Results – Cont.





Delay: $D_{net} \propto \frac{1}{v \cdot M \cdot H^2}$

Lifetime: $T_{net} \propto \frac{1}{H^2}$



Concluding Remarks

- Lifetime and delay aware deployment strategy
- A mobility-aware multi-hop routing protocol (Bounded hop count routing (BHR))
  - To control the trade off between delay, buffer size and lifetime
- Analysis of lifetime, delay, and buffer size
- Optimization problem formulation
- Packet level simulator