Anticipatory Routing For Highly Mobile Endpoints

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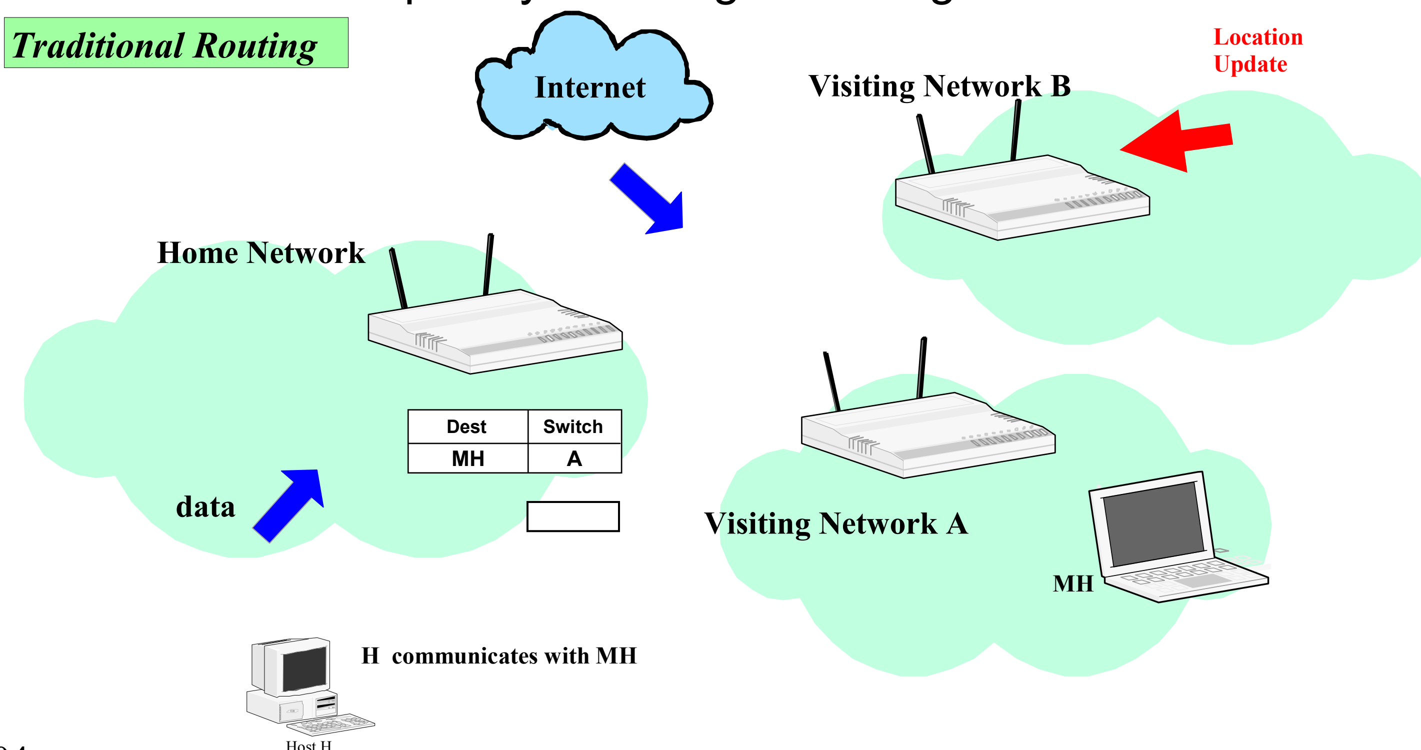
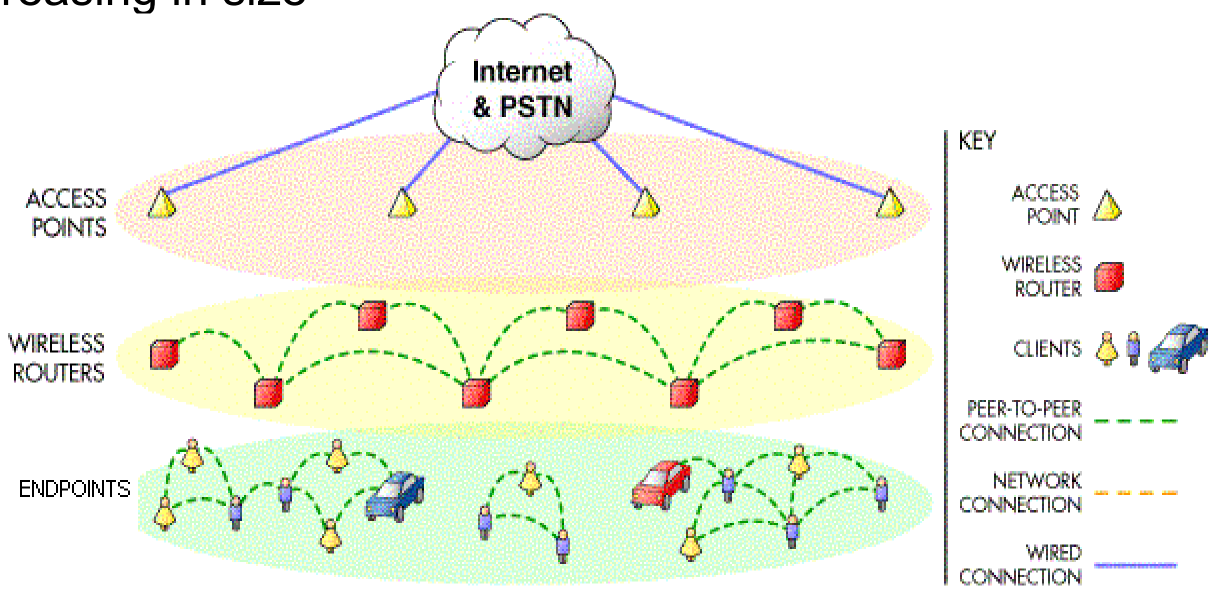
Problem Statement & Motivation

- All Mobile networks employ some control mechanism to route packets to mobile hosts.
  - Efficiency of control mechanism depends on two factors:
    - frequency of location change
    - time it takes to the system to know about that change.
  - But what if the frequency of change is so high?



Problem Statement & Motivation (cont'd)

- Wireless network architectures are evolving toward short links
  - Causes: need for high data rate, scarcity of communication spectrum, need to conserve battery, hence transmission power.
  - Consequence: increase in frequency of changes in network attachment points.
- Wireless network infrastructures (e.g wireless mesh networks/802.16) are increasing in size



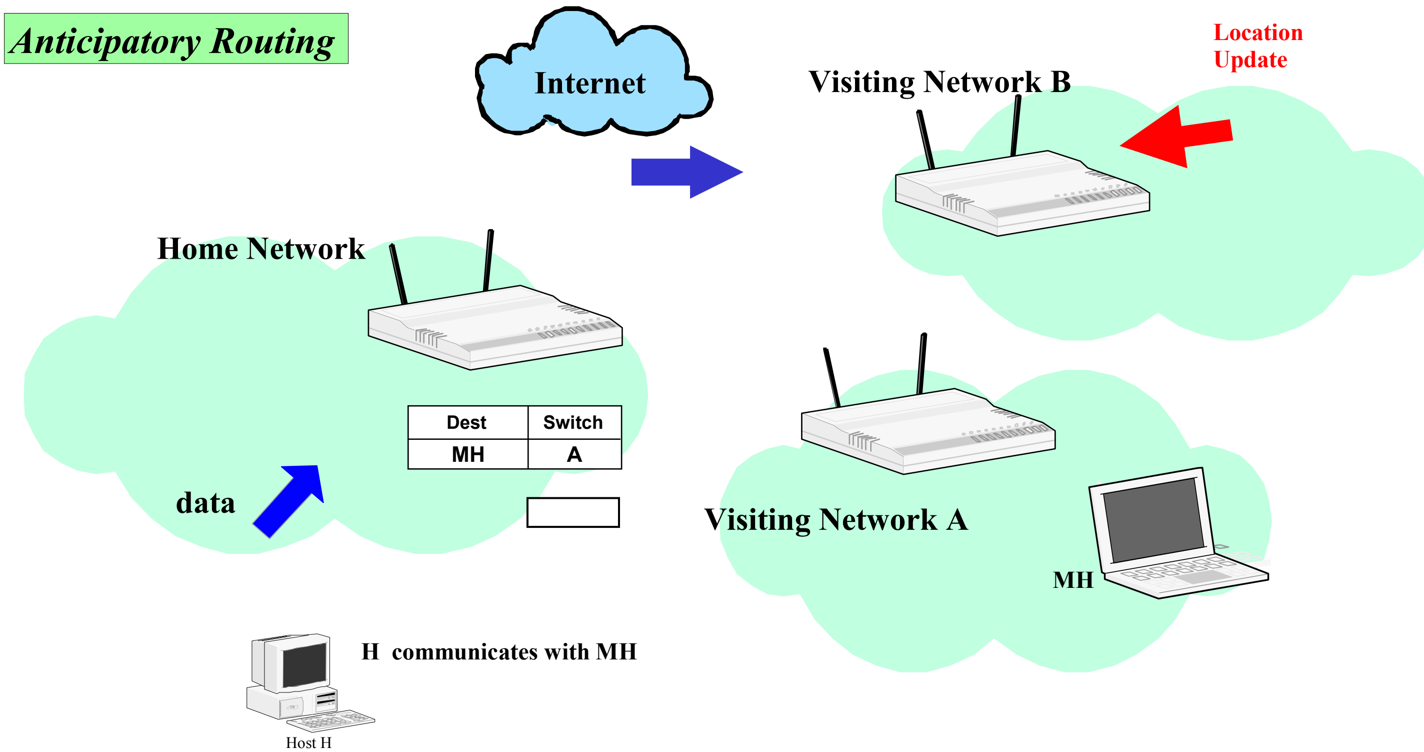
  - Consequence: increase in control message latency, therefore increase in convergence time of the control mechanism.

Problem Statement & Motivation (cont'd)

- Higher frequency of change and higher time of convergence may lead to situations where control mechanism is constantly outpaced by endpoint's mobility
- It is not the absolute speed that matters, but its relation to cell size and convergence time of the system, hence notion of *effective mobility*
- *Effective mobility (M_{eff})= convergence time / cell presence time*
  - When $M_{eff} > 1$, the system is constantly outpaced by endpoint's mobility and we say that the *reactive limit* has been reached

Problem Statement & Motivation (cont'd)

- For mobility regimes that take system beyond reactive limit, a predictive (or anticipatory) mechanism is required.



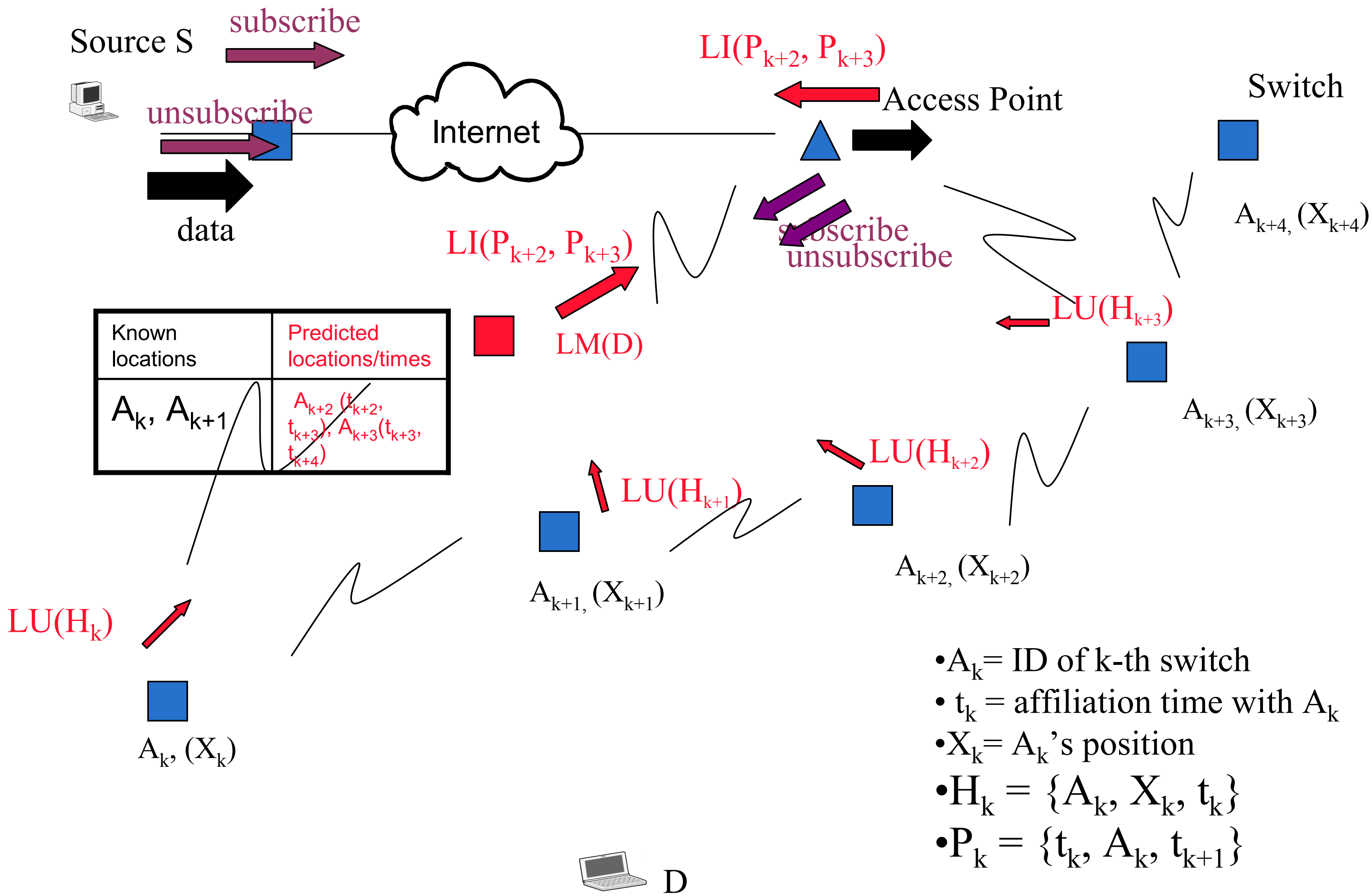
Related Work

- *Spray Routing (SR)* attempts to address the problem of high mobility
  - SR multicasts data traffic in the vicinity of the last "known" location
  - Pros: SR improves the delivery rate
  - Cons: SR generates a significant overhead in duplicate data with increased mobility. SR is not effective beyond a certain effective mobility.
- A small amount of previous research has investigated ideas similar to "prediction of future locations based on history information"
  - *Niculescu, Nath* presents *Trajectory-Based Forwarding (TBF),* a method to forwards packets in a dense MANET based on a predefined trajectory curve.
  - *Pathirana, et all* propose a *Robust Extended Kalman Filter (REKF)* as an estimator in predicting the mobile user's trajectory.
  - *Liu, Maguire* propose a *pattern matching/recognition-based mobile motion prediction (MMP)* to estimate the user mobility.
- Anticipatory Routing is different from existing work in one key aspect: the reactability of the location tracking mechanism.

Context For Our Study

- Studying "Anticipatory Routing" required provision of a context for "Anticipatory Routing" operation
  - Architecture is generic enough, i.e, not tied to a particular standard
- Our network consists of *Switches* and *Endpoints*
  - An endpoint affiliates with a one-hop away switch.
  - Switch can handle one or more endpoints
  - Endpoint's affiliation is done proactively.
  - Switches are GPS-capable: GPS provides time synchronization and position information
- Traffic is stream-oriented (packetized voice, video)
- Our location tracking mechanism is rudimentary and borrows ideas from several known approaches
  - K switches act as location managers (LM).
  - An endpoint is mapped into one LM based on a simple hash. Endpoint updates LM through Location Update.
  - At session setup time, source subscribes with LM of destination.
- Routing protocol is a flat link-state protocol among switches.

Anticipatory Routing



- A_k= ID of k-th switch
- t_k = affiliation time with A_k
- X_k= A_k's position
- $H_k = \{A_k, X_k, t_k\}$
- $P_k = \{t_k, A_k, t_{k+1}\}$

Anticipatory Routing (cont'd)

- Location Manager (LM) uses three basic steps to determine future locations and affiliation times
  - *Estimation of the endpoint's trajectory* as follows:

    L = 2

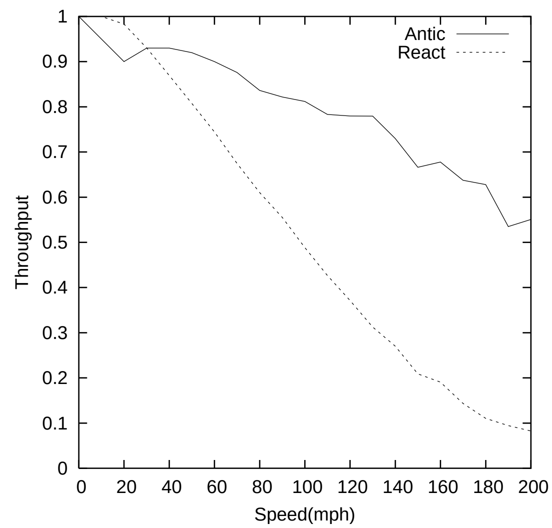
    1. LM picks L and (L+1) latest positions ($X_{k-L-1}..X_k$) and ($X_{k-L}..X_k$)
    2. For each set, LM derives two linear equations (m_1,h_1) & (m_2,h_2)
    3. From (m_1,m_2), directions (θ_1,θ_2) are determined
    4. If $|\theta_1-\theta_2| > \theta_{thresh}$, then endpoint has "turned" and (m_1,h_1) becomes the trajectory equation. Otherwise, L=L+1; goto step 1, etc..
  - *Estimation of the endpoint's direction* θ
    - Θ is determined from slope m, current position X_k and oldest history position X_{k-t}
  - *Estimation of future location, affiliation/departure time*
    - Future locations are derived from (m, h), last known position X_k and network topology
    - Affiliation/departure times to/from switch regions are a function of inter-switch distance, estimated speed, switch diameter, etc..
- Upon data forwarding, switch-source selects final location based on delay estimate and set of anticipated locations and affiliation/departure times

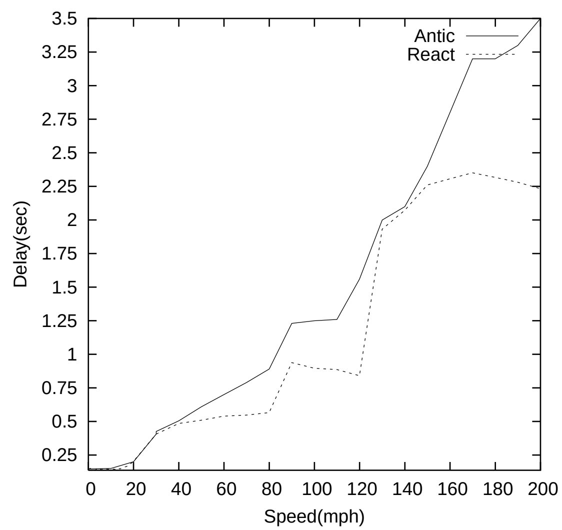
Anticipatory Routing (cont'd)

- Experimental Environment
  - Simulator built from scratch using C++ to independently control performance between fidelity and running time.
  - Multihop wireless network generated by placing a set of S switches and E endpoints in an L x L square area.
    - S = 100; E=40; L=1km; switch radius = 80 meters
  - Switches are static
  - Free-space propagation with threshold cutoff.
  - Mobility model is an extended random walk model.
  - Area model is a "wraparound" model: no area boundary.
  - Queuing delay at each node is modeled: packet is delayed by a time roughly proportional to the congestion.
  - Traffic is stream-oriented
    - Packets within a session generated by bernouilli trials
    - Data rate = 200 kbps
  - This parameters reflect future trends, including an increased reliability on wireless relays to extend the reach.

Anticipatory Routing (cont'd)

- *Throughput (packet delivery ratio)*, *Anticipated Fraction* and *Delay* are metrics of interest
- Analysis
  - AR does worse than traditional routing (TR) for speeds < 30mph
  - AR throughput ~92% around 30mph
  - AR performs better than TR above 30mph (throughput > 50%)
    - Loss-tolerant applications can benefit from this
  - Both AR and TR give rise to higher delays with increasing speed
    - Control message latency increases with frequency of affiliations, resulting in higher queueing delays





Conclusion

- Anticipatory Routing (AR) is a novel mechanism that addresses the problem of routing to highly mobile endpoints
  - AR improves throughput by 56% compared to traditional routing mechanisms <u>in all cases studied</u>
- In practice, AR might be applicable to
  - wireless broadband networks (e.g: wireless-MANs/“mesh extension”) with a large and dense mobile user base
  - tactical networks with truck-mounted routers where situation awareness update of video/imagery data is critical

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