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?

Visiting Network A
Host H
MH
MH communicates with MH

Visiting Network B

Home Network

Traditional Routing

Internet
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

Source S

Internet

Access Point

Switch

Known locations

Predicted locations/times

A_k, A_{k+1}

A_k+2, A_{k+2}, t_{k+2}, A_{k+3}, A_{k+3}(t_{k+3}, t_{k+4})

A_k, (X_k)

A_{k+1}, (X_{k+1})

A_{k+2}, (X_{k+2})

A_{k+3}, (X_{k+3})

A_{k+4}, (X_{k+4})

LI(P_{k+2}, P_{k+3})

LM(D)

LI(P_{k+2}, P_{k+3})

LU(H_{k+3})

LU(H_{k+2})

LU(H_{k+1})

LU(H_k)

\( A_k \) = ID of k-th switch

\( t_k \) = affiliation time with \( A_k \)

\( X_k \) = \( A_k \)'s position

\( H_k = \{ A_k, X_k, t_k \} \)

\( P_k = \{ t_k, A_k, t_{k+1} \} \)

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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 \( (X_{k-L}, X_k) \) 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 \( (\theta_1, \theta_2) \) are determined
    4. If \(|\theta_1 - \theta_2| > \theta_{\text{thresh}}\) 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* \( \theta \)
    • \( \theta \) 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

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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 in all cases studied
• 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