Design and Performance Analysis of Mobility Management Schemes based on Pointer Forwarding for Wireless Mesh Networks

Accepted by IEEE Transactions on Mobile Computing (TMC), 2010

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2010-11-1
Overview

- Introduction
- Types of Mobility Management schemes in WMNs
- System Model
- Static and Dynamic Anchor Schemes
- Performance Model
- Performance Analysis
- Conclusion
Wireless Mesh Networks (WMNs)

- Wireless Mesh Network (WSN) is a network made up of radio nodes organized based on **mesh** networking.

- WSNs often consist of
  - Mesh clients (MC)
  - Mesh routers (MR)
  - Gateways (MR that connect to Internet)

- Major expected in WMNs
  - Providing last-mile broadband internet access
  - MC can move freely within WMN’s range

- Advantages over Traditional Network
  - Low Cost
  - Easy Deployment
  - Self – organization and Healing
  - Compatibility with existing wired and wireless network through gateway(s)
Design and Performance Analysis of Mobility Management Schemes based on Pointer Forwarding for Wireless Mesh Networks

Mesh Networking
Mobility Management

- Mobility Management Consists of
  - Location management (Keep Track of MC location and location update)
  - Handoff management (Maintain connection while MC move around)

- Allows MC to move freely within WMNs range and frequently change their point of attachment (MR)

- Mobility management in Cellular and Mobile IP networks not appropriate for WMNs
  - Lack of Centralized Management
  - HLR/VLR in Cellular Networks
  - HA/FA in Mobile IP Networks

- Ideal Mobility Management for WMNs
  - Per-user based Mobility Management Schemes
    - Optimal setting to individual MC to minimized overall network traffic
Types of Mobility Management schemes in WMNs

- A lot of Mobility Management schemes are studied in Cellular and Mobile IP. 
  *Yet, it is unknown in WMNs.*

- Mobility Management fall into three categories:
  - Tunneling-based Schemes
    - Ant
    - \( M^3 \)
  - Routing-based Schemes
    - iMesh
    - Mesh networks with Mobility Management. (MEMO)
    - WMM (Overview)
  - Multicasting-based Schemes
    - SMesh
Tunneling-based Schemes

- **Ant**
  - Supports Intra-Domain mobility within WMN
  - Use MAC-layer to speedup handoff
  - Disadvantage
    - Signaling cost of location update is considerably high
    - Location update message has to be sent to a central location server every time MC change its point of attachment
    - Worst when average mobility of MC is High

- **M³**
  - Proposed by Huang et al.
  - Combine per-host routing and tunneling to forward packets to MC
  - Location database and User profiles are store within gateway
  - Adopts Periodic location update approach and location update interval is uniform for all MC
  - Disadvantage
    - Can not guarantee optimal performance for every MC
Routing-based Schemes

- **iMesh**
  - Adopts a cross-layer approach
  - Link layer handoff triggered when MC move out of Covering area of its current serving MR
  - used Optimized Link State Routing (OLSR) protocol to broadcasts an HNA message announcing the new route of MC
  - Disadvantage
    - Significant overhead due to the HNA message

- **MEsh networks with MObility Management (MEMO)**
  - Implementation of an applied WMN with support of mobility management
  - Use Modified AODV routing protocol, AODV-MEMO
  - Adopts MAC-layer Triggered Mobility Management (MTMM) like *Ant*
  - Reducing handoff latency
  - Disadvantage
    - The use of flooding in location handoffs leads to high signaling cost and band width consumption
Routing-based Schemes (cont.)

- Wireless mesh Mobility Management (WMM)\cite{huang2008design}
  - Location update and location information synchronization done while mesh routers route packets
  - Reduce signaling overhead

Multicasting-based Schemes

- SMesh
  - Offer seamless wireless mesh network system to MC
  - MC view system as a single access point
  - Fast handoff
  - Disadvantages
    - High signaling cost, especially when the average mobility rate of MC is high
    - Management of Multicasting groups is also a major source of signaling overhead
Contributions of this Paper

- Static and Dynamic Anchor Schemes
  - Base on Pointer Forwarding (Chain of pointer keeping track of the current location of MC)

- Analytical Models based on stochastic Petri nets (SPN)
  - Evaluate and compare performance between the proposed schemes and the existing schemes (Wireless mesh Mobility Management, WMM)

- Static vs. Dynamic Anchor Schemes (Overview)
  - Dynamic Schemes is better in Typical network condition
  - Static Schemes is better when the service rate of MC is high

- Proposed Schemes vs. WMM (Overview)
  - Proposed Schemes are better when network traffic is dominated by internet application
    (When traffic load on the downlink is larger than uplink)
System Model

- WMN consists of
  - Mesh Routers (MR)
    - Some MR connect to internet are call Gateways
  - Mesh Client (MC)
    - Move freely within WMNs

- Mobility management (Static and Dynamic Anchor Schemes)
  - The central location database resides in the gateways.
    - Every MC within WMNs have a location information in location database.
      - Also call, “The address of its anchor MR (AMR)”
        - AMR of an MC is the head of its forwarding chain
  - Any data packets sent to MC will go to AMR and then follow the forwarding chain to reach MC
  - Both Static and Dynamic Anchor Schemes simply rely on the concept of *Pointers Forwarding*
Pointer Forwarding

- Originally from Mobility Management Schemes in Cellular network.

- Purpose is to minimized the overall network signaling cost from Mobility management operation. (number of Location update event)

- Location Update Event
  - Sending a location update message to gateways to inform gateways to update location database.
  - With pointer forwarding, Location Handoff only involves setting up a forwarding pointer between two neighboring MRs without trigger Location Update Event

- Forwarding chain length of MC is greatly affects the Mobility Management and Packet Delivery Cost
  - The longer Chain length, the lower rate the location update event (reducing signaling overhead)
  - HOWEVER, The packets delivery cost will increase as the chain length increase
Pointer Forwarding
Signal Cost vs. Service Cost
Trade-off

- There exists an optimal threshold of the *Chain Length* for each MC

- In Static and Dynamic Anchor Schemes, optimal threshold is denoted by $K$
  - $K$ determined for each MC individually based on the MC’s specific mobility and service patterns
  - Service to Mobility Ratio (SMR) is used to depict the MC’s Mobility and Service Patterns for each MC
  - For MC with average packets arrive rate denoted by $\lambda P$ and mobility rate denoted by $\sigma$
    - SMR is Formally defined as $\text{SMR} = \frac{\lambda P}{\sigma}$
Internet Traffic in WMNs

- Traffic between MRs and the gateway dominates peer to peer traffic
  - WMNs expect to be low-cost solution for providing last-mile broadband internet access
  - Therefore, Internet arrival rate higher than Intranet arrival rate
    - Let $\gamma$ denote the ratio between internet arrival rate to intranet arrival rate
  - The average duration of internet sessions is also longer than intranet sessions
    - Let $\delta$ denoted the ratio between the average duration of internet session to intranet sessions

- We assume that $\delta$ is also the ratio of intranet departure rate to internet
  (Performance Model)
Static Anchor Scheme

- In the static anchor scheme, an MC’s AMR remains unchanged as long as the length of the forwarding chain does not exceed the threshold $K$. 
Static Anchor Scheme (Cont.)

Location
Handoff

AMR
FL=1
MR1
K=2
FL=2
MR2
AMR
MR3

Design an
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1 (TMC), 2010.
Static Anchor Scheme (Cont.)

Internet Session Delivery

AMR
MR1
MR2
MR3
Static Anchor Scheme (Cont.)

Intranet Session Delivery

Design an...
Dynamic Anchor Scheme

- In the dynamic anchor scheme, the current forwarding chain of an MC will be reset due to the arrival of new Internet or Intranet sessions.
- The idea behind this scheme is to reduce the packet delivery cost by keeping the AMR of an MC close to its current serving MR when the SMR is high, thus relieving the problem of triangular routing of the static anchor scheme, with the extra cost of resetting the forwarding chain upon a new session arrival.
Dynamic Anchor Scheme (internet)

1. New session arrival.
2. Execute location search procedure to MC’s current serving MR, which may be different from its AMR.
3. Reset the AMR to the current serving MR.
Dynamic Anchor Scheme (Cont.)

Internet Session Delivery

Gateway (Location Server)

Update message

AMR

AMR

AMR

MC

Internet CN

Internet
Dynamic Anchor Scheme (Cont.)

Intranet Session Delivery
Static Scheme SPN Model

Mark(newMR)=1 means that the MC just moved forward to a new MR.

Mark(FL) indicates the forwarding chain length.

Mark(Movement)=1 means that the MC just moved.

Mark(PreMR)=1 means that the MC just moved backward to the most recently visited MR.
Static Scheme SPN Model

Modeling MC movement

Forward movement

Modeling the event of setting up a forwarding pointer between two neighboring MRs

Backward movement

Modeling the event of removing a forwarding pointer due to a backward movement

Modeling the event of updating the location database and resetting the forwarding chain due to MC movement that causes the threshold \( K \) to be exceeded

Fig. 4. The SPN model for the static anchor scheme.
Dynamic Scheme Del

Modeling the arrival of internet sessions

Modeling the arrival of intranet sessions

A place holding newly arrived internet session

A place holding newly arrived intranet session

Modeling the forwarding chain resetting due to a newly arrived internet session

Modeling the forwarding chain resetting due to a newly arrived intranet session

Fig. 5. The SPN model for the dynamic anchor scheme.
Static Scheme SPN Model: case study

Fig. 4. The SPN model for the static anchor scheme.
Dynamic Scheme SPN Model: case study

5. The SPN model for the dynamic anchor scheme.
# Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>Mobility rate</td>
<td></td>
</tr>
<tr>
<td>$\lambda_I / \mu_I$</td>
<td>Internet session arrival/departure rate</td>
<td></td>
</tr>
<tr>
<td>$\lambda_L / \mu_L$</td>
<td>Intranet session arrival/departure rate</td>
<td></td>
</tr>
<tr>
<td>$\lambda_{pu}$</td>
<td>Average uplink (outcoming) packet arrival rate of Internet sessions</td>
<td></td>
</tr>
<tr>
<td>$\lambda_{pd}$</td>
<td>Average downlink packet arrival rate of Internet sessions</td>
<td></td>
</tr>
<tr>
<td>$\lambda_{pL}$</td>
<td>Average packet arrival rate of Intranet sessions</td>
<td></td>
</tr>
<tr>
<td>$N_{pI}$</td>
<td>Average number of downlink (incoming) packets per Internet session</td>
<td></td>
</tr>
<tr>
<td>$N_{pL}$</td>
<td>Average number of incoming packets per Intranet session</td>
<td></td>
</tr>
<tr>
<td>$N_I$</td>
<td>Instantaneous average number of active Internet correspondence nodes per MC</td>
<td></td>
</tr>
<tr>
<td>$N_L$</td>
<td>Instantaneous average number of active Intranet correspondence nodes per MC</td>
<td></td>
</tr>
<tr>
<td>$N$</td>
<td>Number of MRs in a WMN</td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Average distance (number of hops) between the gateway and an arbitrary MR</td>
<td></td>
</tr>
<tr>
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<td>$\gamma$</td>
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</tr>
<tr>
<td>$\delta$</td>
<td>Ratio of the average duration of Internet sessions to the one of Intranet sessions</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>Ratio of the downlink packet arrival rate to the uplink packet arrival rate of Internet sessions</td>
</tr>
<tr>
<td>$\tau$</td>
<td>One-hop communication latency between two neighboring MRs</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Rate of reconnection when an MC switches from sleep mode back to active mode</td>
</tr>
<tr>
<td>$P_f$</td>
<td>Probability that an MC moves forward</td>
</tr>
<tr>
<td>$P_b$</td>
<td>Probability that an MC moves backward</td>
</tr>
<tr>
<td>$P_g$</td>
<td>Probability that an Intranet packet is routed to the gateway due to unknown location information of the destination MC in the WMM scheme</td>
</tr>
<tr>
<td>$P_q$</td>
<td>Probability that the location query procedure is executed in the WMM scheme</td>
</tr>
<tr>
<td>$P_r$</td>
<td>Probability that an MR broadcasts the route request message in the WMM scheme</td>
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Parameterization

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<th>$\tau$</th>
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$$\mu_{AddPointer} = \frac{1}{2\tau}$$

Fig. 4. The SPN model for the static anchor scheme.
Parameterization

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\[ \alpha \tau + N_L \beta \tau \]

Inform all the active Intranet correspondence nodes of the MC

\[ \mu_{ResetLU} = \frac{1}{(\alpha + N_L \beta) \times \tau} \]

Update location information to gateway

Fig. 4. The SPN model for the static anchor scheme.

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<td>( \beta )</td>
<td>Average distance (number of hops) between two arbitrary MRs</td>
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</table>
Parameterization

\( i = \text{current length of forwarding chain} \)

\[
\mu_{\text{ResetIS}} = \frac{1}{(2\alpha + N_L \beta + i) \times \tau}
\]

5. The SPN model for the dynamic anchor scheme.
Parameterization

\[ \mu_{ResetLS} = \frac{1}{(4\alpha + N_L\beta + i) \times \tau} \]

5. The SPN model for the dynamic anchor scheme.
Parameterization

\[ P_f = \frac{3}{4}, \quad P_b = \frac{1}{4} \]

Fig. 4. The SPN model for the static anchor scheme.
Performance Metrics

\[ C_{\text{static}} = C_{\text{location}} \times \sigma + C_{\text{search,}L} \times \lambda_I + C_{\text{delivery,}I} \times \lambda_{pd} + C_{\text{delivery,}L} \times \lambda_{pL} \]

\[ C_{\text{dynamic}} = C_{\text{location}} \times \sigma + C_{\text{search,}I} \times \lambda_I + C_{\text{search,}L} \times \lambda_L + C_{\text{delivery,}I} \times \lambda_{pd} + C_{\text{delivery,}L} \times \lambda_{pL} \]

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<td>( N_{pL} )</td>
<td>Average number of incoming packets per Intranet session</td>
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Performance Metrics

- Let $P_i$ denote the probability that underlying Markov chain is found in a state that the current forwarding chain length is $i$

\[
C_{location} = \sum_{i} P_i C_{i, location}
\]

\[
C_{i, location} = \begin{cases} 
2\tau & \text{if } 1 \leq i < K \\
(\alpha + N_L \beta) \times \tau & \text{if } i = K
\end{cases}
\]
### Performance Metrics

\[
C_{\text{search}} = \sum_{S} P_{i} C_{i,\text{search}}
\]

\[
C_{i,\text{search},s,L} = 2\alpha \tau
\]

\[
C_{i,\text{search},d,I} = (2\alpha + N_L \beta + i) \times \tau
\]

\[
C_{i,\text{search},d,L} = (4\alpha + N_L \beta + i) \times \tau
\]

\[
C_{\text{delivery}} = \sum_{S} P_{i} C_{i,\text{delivery}}
\]

\[
C_{i,\text{delivery},I} = (\alpha + i) \times \tau
\]

\[
C_{i,\text{delivery},L} = (\beta + i) \times \tau
\]

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Performance Analysis

- Analyze the performance in terms of the total communication cost incurred per time unit
  - Comparing Static and Dynamic Anchor Schemes with two baseline schemes
    - First baseline schemes, pointer forwarding is not used
      - Every movement of MC will trigger location update event. (K=0)
    - Second baseline schemes, pointer forwarding is used
      - For every MC Chain forwarding length is set to 4 (K=4)
  - Comparing Static and Dynamic Anchor Schemes with WMM schemes
### Performance Parameters

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<tbody>
<tr>
<td>$\gamma$</td>
<td>10</td>
<td>$\delta$</td>
<td>5</td>
<td>$\lambda_I$</td>
<td>$\frac{1}{600}$</td>
</tr>
<tr>
<td>$\mu_I$</td>
<td>$\frac{1}{600}$</td>
<td>$N_I$</td>
<td>200</td>
<td>$N_L$</td>
<td>100</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>30</td>
<td>$\beta$</td>
<td>30</td>
<td>$N$</td>
<td>1000</td>
</tr>
<tr>
<td>$P_g$</td>
<td>5.0%</td>
<td>$P_q$</td>
<td>10.0%</td>
<td>$P_r$</td>
<td>50.0%</td>
</tr>
<tr>
<td>$\tau$</td>
<td>1</td>
<td>$\omega_{active}$</td>
<td>$\frac{1}{1200}$</td>
<td>$\omega_{sleep}$</td>
<td>$\frac{1}{600}$</td>
</tr>
</tbody>
</table>

Time unit is in Second, all cost are normalized with respect to $T = 1$
Total communication Cost vs. K

Total communication cost in both schemes decrease, as SMR increase.

*Square-grid mesh network* model for WMNs and the *random walk model* for MCs.

****Under the default value given in Fig. A and these SMR setting. The Dynamic always perform better than Static Schemes. However, when the arrival rate is high, the additional overhead due to resetting MC chain upon new session arrival will offset it advantage.

\[
C_{\text{static}} - C_{\text{dynamic}} \text{ vs. SMR}
\]

Set
\[
\mu I = \frac{1}{30}, \quad \lambda I = \frac{1}{30}
\]

We can see that, as SMR increase the cost different became smaller and there exist a crossover point which Static Schemes performing better than Dynamic Schemes.
Optimal K vs. SMR

As optimal K decrease, SMR increase. Therefore a short forwarding chain is favorable to reduce service delivery cost.

****Note that Static anchor schemes optimal K always smaller or equal to Dynamic anchor schemes.

Cost difference vs. SMR between proposed schemes and baseline schemes

We can see that both proposed schemes performing better than the baseline schemes, especially when SMR is small.
WMM is a routing-based mobility management schemes

Location management is integrated with packet routing
- This idea is earlier adopted by Cellular IP and HAWAII
  - Both are routing-based micro-mobility management schemes for Mobile IP networks.

Each MR in WMM employs a Proxy table to store location information of MC for which it has routed packet
- Every IP header of data packet contain a Location Information
Total Communication Cost vs. $\zeta$ in WMM

Let $\zeta$ denote the ratio of the downlink packet arrival to uplink packet arrival rate to internet sessions. $\zeta$ is expected to be fairly large:

$$C_{reconnect} = \alpha T$$

$\zeta_c$ vs. SMR

We can see that $\zeta_c$ is decrease at first when SMR increase. However, as SMR keep increasing, $\zeta_c$ also start to increase as well. This is because WMM favors small mobility rate, but as SMR increase WMM performance will start to drop quickly at some point.
Proposed Schemes vs. baseline schemes, under two different combination of \( \alpha \) and \( \beta \)

The proposed schemes perform a lot better than the baseline schemes, especially when SMR is small.

Sensitivity Analysis

Total communication cost vs. \( K \), assuming the hexagonal network coverage model

Similar graph to Fig. 6, we can say that the analytical result are valid and not sensitive to network coverage model.
Conclusion

- Two proposed Schemes for WMNs base on pointer forwarding and per-user based
  - Static Anchor Schemes
  - Dynamic Anchor Schemes

- The total chain length that minimized the total communication cost is dynamic determined for individual MC based on the MC’s specific mobility and service patterns characterized by SMR

- Comparing Two proposed schemes with two baseline schemes and WMM
  - Dynamic Anchor Schemes perform better than Static Anchor schemes in typical network condition
  - Static Anchor Schemes is better when service rate of an MC is comparatively high, such that the advantage of Dynamic Anchor Schemes will be offset by it overhead
  - Both Dynamic and Static Anchor Schemes perform better than baseline schemes, especially when SMR is small
  - Dynamic Anchor Schemes is superior to WMM when network traffic for which downlink packet arrival rate is much higher than uplink packet arrival rate.
My comments

- The WMNs scenarios have multiple gateways should be considered
- More realistic mobility models rather than random walk model should be investigated
- Signaling cost optimization is needed while considering the caching on MCs, i.e., a optimization formulation is required.
- ...

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Thank you!!

- Question || Comment??