A Comprehensive and Efficient Handoff Procedure for IPv6 Mobility Support

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duplicate address detection
neighbor discovery
movement detection
Mobile IPv6
Overall Handoff Procedure

upon link-layer trigger

movement detection

IP link change?

yes

removal of stale global IP addresses

default router selection

duplicate address detection for link-local IP address

upon Router Advertisement

router and prefix discovery

address configuration of global IP addresses

duplicate address detection for global IP addresses

Mobile IPv6 registrations
Router Discovery

- To discover routers and on-link prefixes
- Routers advertise this information
  - Periodically in unsolicited Router Advertisements
  - In response to Router Solicitations
- Intervals for unsolicited Router Advertisements configurable; minimum is 3s~4s
  - Jitter desynchronizes multiple routers on same link
  - $\leq 3.5s$; receive first $\leq 1750ms$ after handoff
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- $\Omega 3.5s$; receive first $\Omega 1750ms$ after handoff

Delays too high to support mobility
Send Router Solicitation upon handoff

- Must be sent from unspecified IP address
  - Elicits multicast Router Advertisement
- Rate limitations (only 1/3s) + 500ms desynchronization
  - Reception $\Omega$ 1750ms after handoff when mobility high
Send Router Solicitation upon handoff
- Must be sent from unspecified IP address
  - Elicits multicast Router Advertisement
- Rate limitations (only 1/3s) + 500ms desynchronization
  - Reception $\varnothing$ 1750ms after handoff when mobility high

Not really an advantage over unsolicited Router Advertisements
Router Advertisement intervals 30ms~70ms

- Ø 50ms; reception Ø 25ms after handoff
- No comparable improvement for solicited Router Advertisements

![Diagram showing router advertisement intervals and reception times](image-url)
Router Advertisement intervals 30ms~70ms

- Ø 50ms; reception Ø 25ms after handoff
- No comparable improvement for solicited Router Advertisements

Better, yet still sub-optimal in terms of delay and bandwidth consumption
Address Configuration

- To configure unicast IP addresses
  - Global address for each new prefix
  - Link-local address upon first network attachment
  - Uniqueness re-verification for link-local address upon change in IP connectivity
- Stateless and stateful variant
- Generate new IP address
  - Choose interface identifier based on MAC address
  - Prepend on-link prefix
- Send MLD Report for solicited-node multicast address
  - Up to 1s desynchronization between nodes responding to same Router Advertisement
- Duplicate Address Detection
  - Send Neighbor Solicitation
  - Listen for Neighbor Advertisement for 1s
  - Defending node would send Neighbor Advertisement
Address Configuration à la RFC 2462

- Generate new IP address
  - Choose interface identifier based on MAC address
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  - Defending node would send Neighbor Advertisement

Diagram:
- Generate new IP address
- MLD Report
- Neighbor Solicitation
- Neighbor Advertisement
- 500ms
- Failure: manual config required
- Generate new IP address
  - Choose interface identifier based on MAC address
  - Prepend on-link prefix
- Send MLD Report for solicited-node multicast address
  - Up to 1s desynchronization between nodes responding to the same Router Advertisement
- Duplicate Address Detection
  - Send Neighbor Solicitation
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  - Defending node would send Neighbor Advertisement

Delays too high to support mobility
Stateful Address Configuration

- DHCPv6 server assigns global address
- High latency
  - Duplicate Address Detection for link-local address first
    - Includes up to 1s desynchronization for MLD Report
  - DHCPv6 servers desynchronize responses for 1.0~1.1s
  - Duplicate Address Detection for global address
Stateful Address Configuration

- DHCPv6 server assigns global address
- High latency
  - Duplicate Address Detection for link-local address first
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  - DHCPv6 servers desynchronize responses for 1.0~1.1s
  - Duplicate Address Detection for global address

Delays even higher than in stateless address configuration
Movement Detection

- To determine changes in IP connectivity
  - Link-layer trigger necessary, but not sufficient
  - Changes in IP connectivity $\subset$ changes in link-layer attachment

- Change in IP connectivity requires...
  - Invalidation of stale global IP addresses
  - Default router change
  - Uniqueness re-verification of link-local IP address
  - Mobile IPv6 registrations

- Monitoring of on-link prefixes
  - Prefix sets of different links disjoint
    - Old prefixes no longer seen, but new instead $\Rightarrow$ IP link change likely
    - Link-layer trigger, but same prefixes $\Rightarrow$ no IP link change
Movement Detection

- Problems
  - Different routers may advertise different prefix sets
    - Router Advertisements from 1 on-link router insufficient
  - Router Advertisements may contain incomplete prefix sets
    - 1 Router Advertisement from each on-link router insufficient
  - Packet loss
    - 1 missing Router Advertisement insufficient
    - Interval between Router Advertisements unknown
- Partial solution: Advertisement Interval option for Router Advertisements (RFC 3775)
  - Indicates upper interval bound
    - Old default router unreachable when 3 Router Advertisement missed
  - 20ms increment if interval < 200ms
    - To account for scheduling granularities
  - Configured interval 30ms~70ms ⇒ advertised interval 90ms
Movement Detection

- Detection of change in IP connectivity:
  - Router Advertisement
  - 90ms
  - 90ms
  - 90ms

- Detection of new prefixes:
  - Router Advertisement
  - 25ms
  - 50ms
  - 50ms
  - 50ms
Mobile IPv6

- To resume active communication sessions after IP address change
- To maintain reachability for inbound session requests
Mobile IPv6

@ home address

home link

visited link

Internet

being at home
Mobile IPv6

binding between home and c/o address
Mobile IPv6

route optimization
Mobile IPv6

verIFICATION OF
HOME ADDRESS

verIFICATION OF
C/O ADDRESS

home agent
Only now does correspondent node learn about new c/o address.
Related Work

- FastRA improves router discovery
  - Node solicits immediate Router Advertisement
  - Distributed algorithm defines order in which to respond
Related Work

- Optimistic Duplicate Address Detection improves address configuration
  - Node may use new IP address during verification,…
  - but may not disrupt other nodes' neighbor caches

Related Work

<table>
<thead>
<tr>
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![Diagram](image)
Related Work (More in the Paper…)

- DNA protocol improves movement detection
  - Link identifiers, landmarks ease movement detection
  - 1 Router Advertisement enough to detect link change

![Diagram showing IP address generation and movement detection processes]

- Router Advertisement
- Neighbor Solicitation
- MLD Report
- Router Solicitation

Detect change in IP connectivity

- Generate new IP address
- w/o delay

Address tentative, but usable
Proposed Mobile IPv6 Optimizations

- Early Binding Updates, Credit-Based Authorization

  - proactive home address test
  - parallel home and correspondent registration
  - concurrent c/o address test

  home agent

  - Home Test Init
  - Home Test
  - Binding Update
  - Early Binding Update
  - Care-of Test Init
  - Binding Ack
  - Early Binding Ack
  - Care-of Test
  - Binding Update
  - Binding Ack

  early, tentative registration
  use unverified c/o address with Credit-Based Authorization

  full registration
Proposed Mobile IPv6 Optimizations

- Early Binding Updates, Credit-Based Authorization

Diagram:
- Home Test Init
- Home Test
- Binding Update
- Early Binding Update
- Care-of Test Init
- Binding Ack
- Early Binding Ack
- Care-of Test
- Binding Update
- Binding Ack

Key:
- 1st packet
- 1 RTT
- Home agent
- early, tentative registration
Comparison of Handoff Procedures

- Ø 25ms:
  - Router Adv.
  - MLD Report
  - Neighbor Sol.
  - Binding Upd., Ack

- Ø 500ms:
  - MLD Report
  - Neighbor Sol.

- 1s:
  - Binding Upd., Ack
  - Home Test [Init]

- 4 RTT:
  - Care-of Test [Init]
  - Binding Upd., Ack

- 1 RTT no delay:
  - Router Sol.
  - Router Adv.
  - MLD Report
  - Neighbor Sol.
  - [Early] Binding Upd.
  - Care-of Test [Init]
  - Binding Upd., Ack

Local router

Proactive home address test not shown
Conclusions and Future Work

- Handoff delays for standard auto-configuration substantial
  - Delays due to conservative advertisement frequencies, desynchronization, and duplicate address detection
  - Optimizations have enormous impact
    - Eliminate desynchronization delays
    - Use tentative IP addresses during duplicate address detection
    - More informative Router Advertisements to ease movement detection
    - Apply proactivity, concurrency, and parallelism in Mobile IPv6
- Mobility protocol optimizations only useful in conjunction with auto-configuration optimizations
- Future work on proactive handoff management