Cross-layer mobility management in support of seamless handovers

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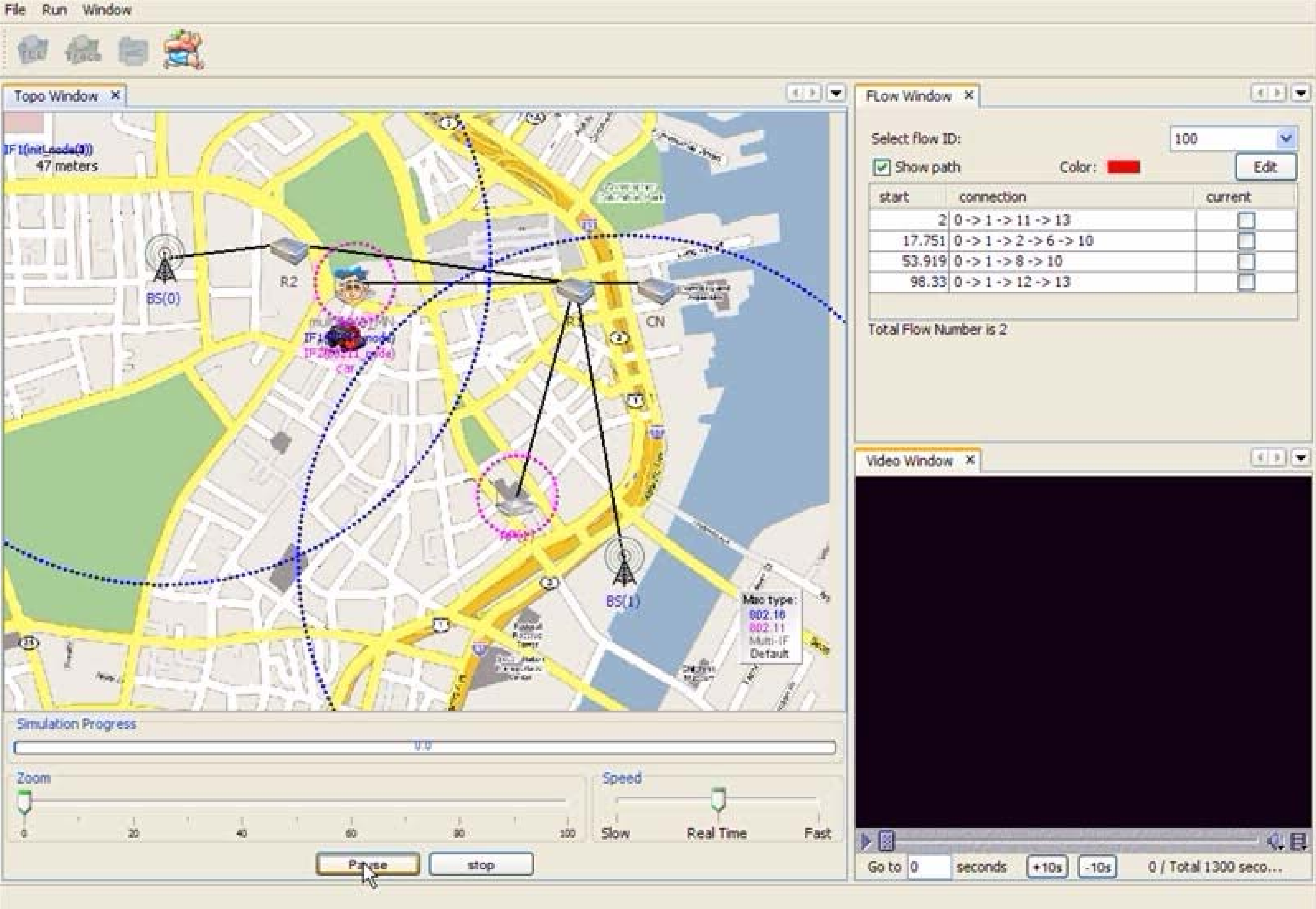
Outline

- What are seamless handovers?
- Do we care?

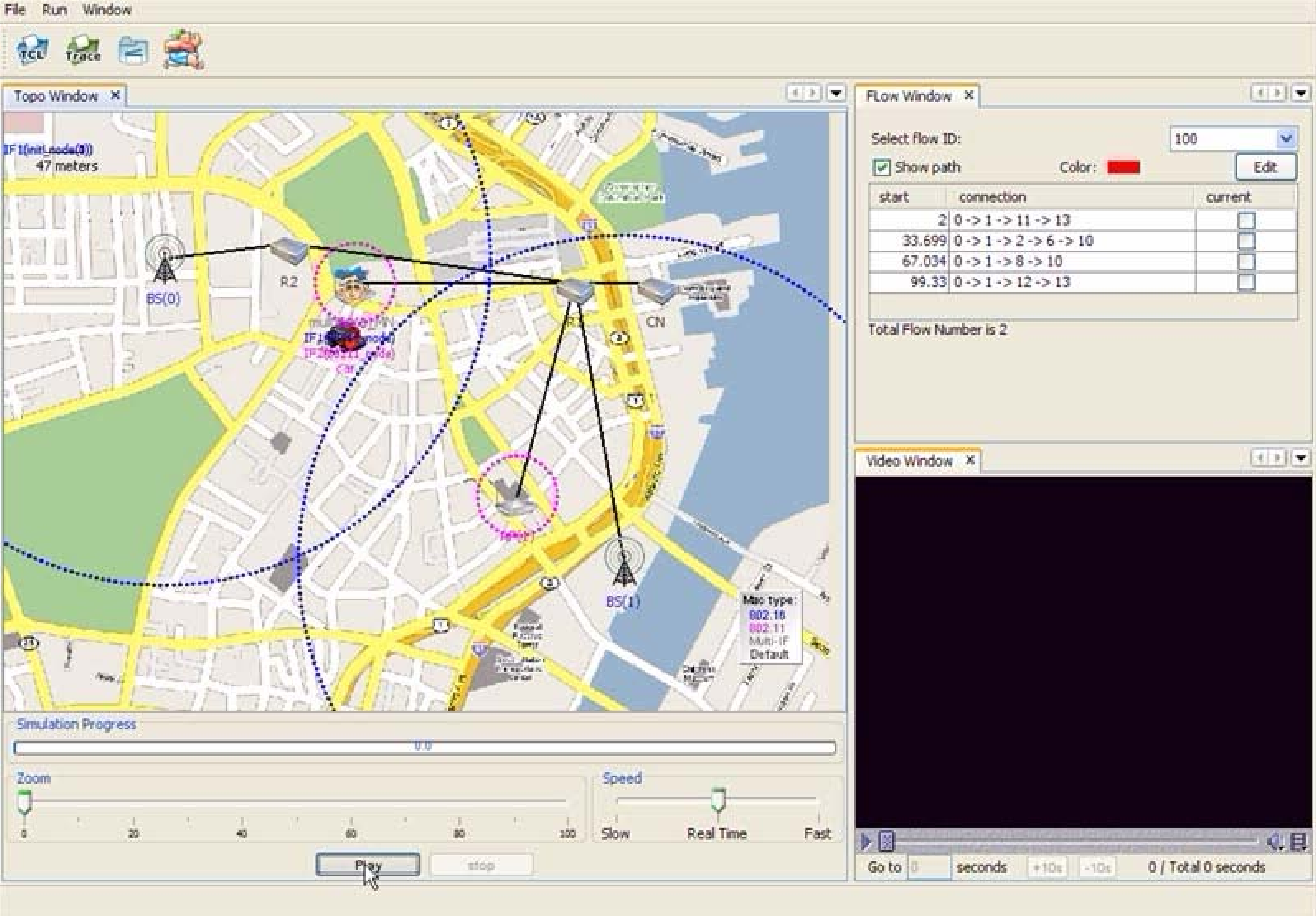
  Short demo using NS2 Viz Net
- How to achieve seamless handovers?
- Cross-layer mobility management
  - Network monitoring
  - Link event triggers
  - Neighbor discovery
  - Network selection
  - Connection set-up
  - Route update
- Time-based link triggers
- References and useful links

What are seamless handovers?

Seamless mobility is the ability for a user to roam across different networks while staying connected.



File Run Window
Topo Window
47 meters
BS(0)
R2
R1
CN
car
BS(1)
Mac type:
802.16
802.11
Multi-IF
Default
Simulation Progress
Zoom
0
20
40
60
80
100
Speed
Slow
Real Time
Fast
Pause
stop
FLow Window
Select flow ID:
100
Show path
Color:
Edit
start
connection
current
2 0 -> 1 -> 11 -> 13
17.751 0 -> 1 -> 2 -> 6 -> 10
53.919 0 -> 1 -> 8 -> 10
98.33 0 -> 1 -> 12 -> 13
Total Flow Number is 2
Video Window
Go to 0 seconds +10s -10s 0 / Total 1300 seco...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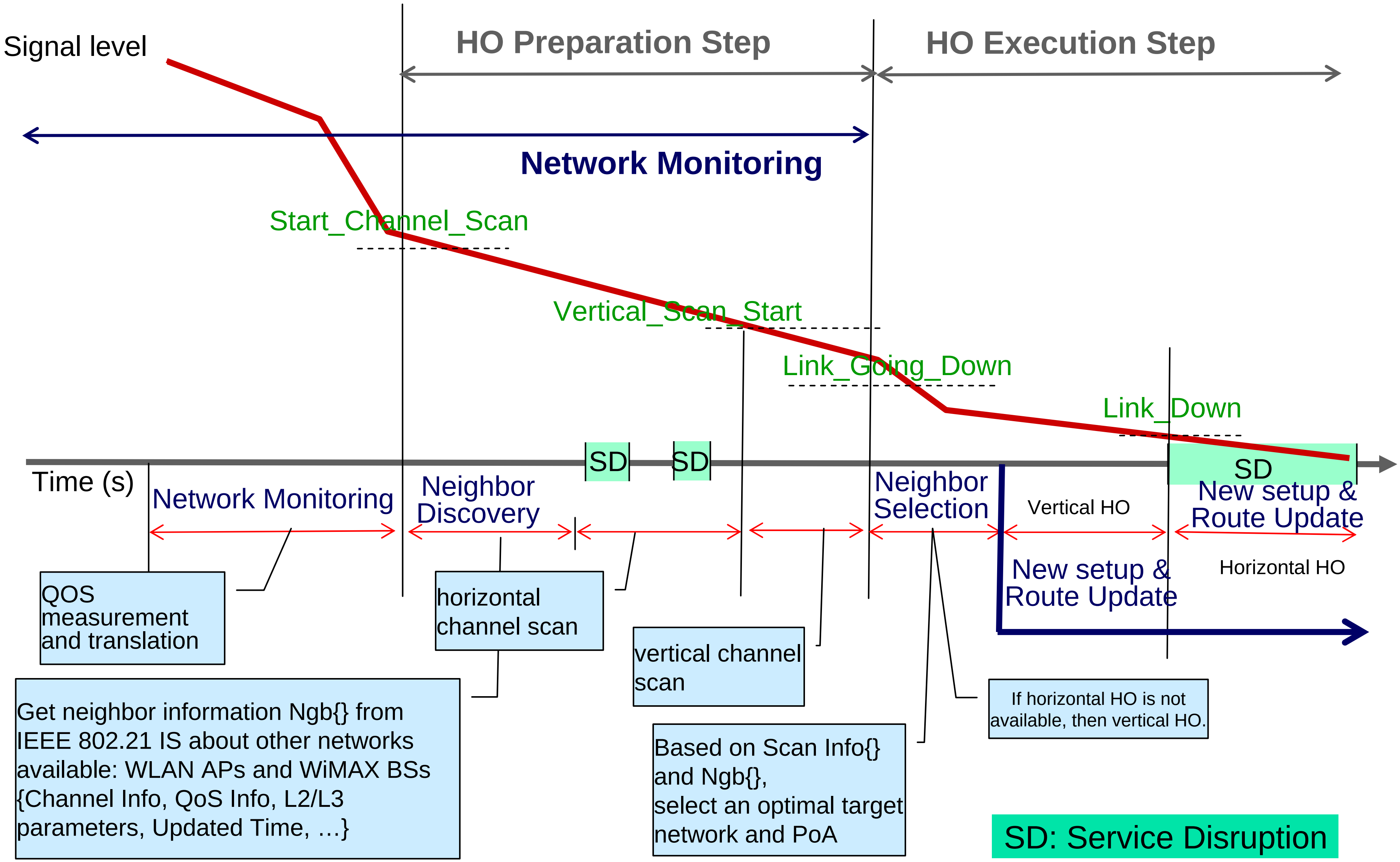
FLow Window
Select flow ID:
100
Show path
Color:
Edit
start
connection
current
2
0 -> 1 -> 11 -> 13
33.699
0 -> 1 -> 2 -> 6 -> 10
67.034
0 -> 1 -> 8 -> 10
99.33
0 -> 1 -> 12 -> 13
Total Flow Number is 2
Video Window
Go to
seconds
0 / Total 0 seconds

A closer look at handovers events



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Service disruptions

ITL Information Technology Laboratory

Step	Link Disconnection?	Function
Network monitoring	No	Measure QoS on current link
Neighbor discovery	Horizontal: Partial Vertical: No	Channel scanning and QoS information
Network selection	No	▪ Target PoA decision (including vertical) based on the obtained information.
New Connection setup	Horizontal: Yes Vertical: No	▪ Link disconnected with old PoA, and link connection to new PoA (horizontal) ▪ Vertical interface activation and network entry (vertical)
Route update	Horizontal: Yes Vertical: No (little access delay)	▪ Mobile IP L3 Handover

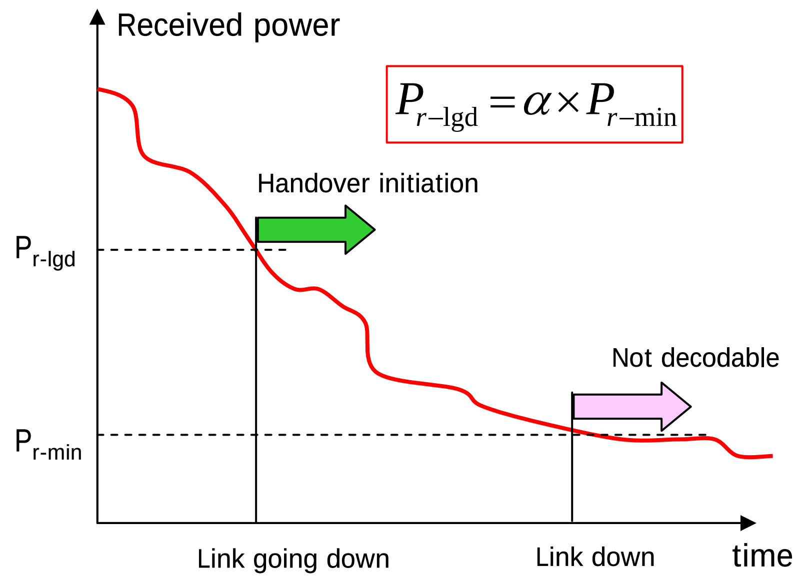
- For a single interface radio, perform horizontal handover:
  - There will be service disruptions to perform channel scanning and obtain QoS information from neighbor PoAs.
  - There will also be service disruptions to perform L2 switching and new connection set-up including network entry and route update
- For a multiple interface radio, perform vertical handover:
  - During the handover execution step, there is no link disconnection
  - Some L3 MIPv6 messages are exchanged in order to update the route information in addition to L2 frames are exchanged which may cause higher access delays.

Achieving seamless handovers: optimizing performance

- Neighbor discovery
  - Direct discovery involves channel scanning
  - Channel scanning in single radio devices results in service disruption (loss and delay)
  - Indirect discovery via information service to obtain short channel list
  - Supporting QoS during channel scanning requires pre-scan information and scan order
- Network selection
  - Based on channel scanning results estimate the expected QoS of each candidate PoA
  - Decide on a target network and PoA given selection criteria including cost, QoS etc.
- Connection set-up and route update
  - Authentication is time consuming
  - Pre-authenticate or quickly re-authenticate with AAA server
  - Predictive fast mobile IP
- Link event trigger
  - All necessary handover functions (including above) should be completed before the current link is broken.
  - Timely updates are critical!!

Link event triggers

- Are sent from layers 1 and 2 to give updates on the link conditions
- Most triggers are set based on a pre-determined threshold of the signal quality measure.
- For example, power level ($P_{r\text{-}lgd}$) is used.
  - $P_{r\text{-}lgd}=\alpha * P_{r\text{-}min}$
  - α is fixed and conservative



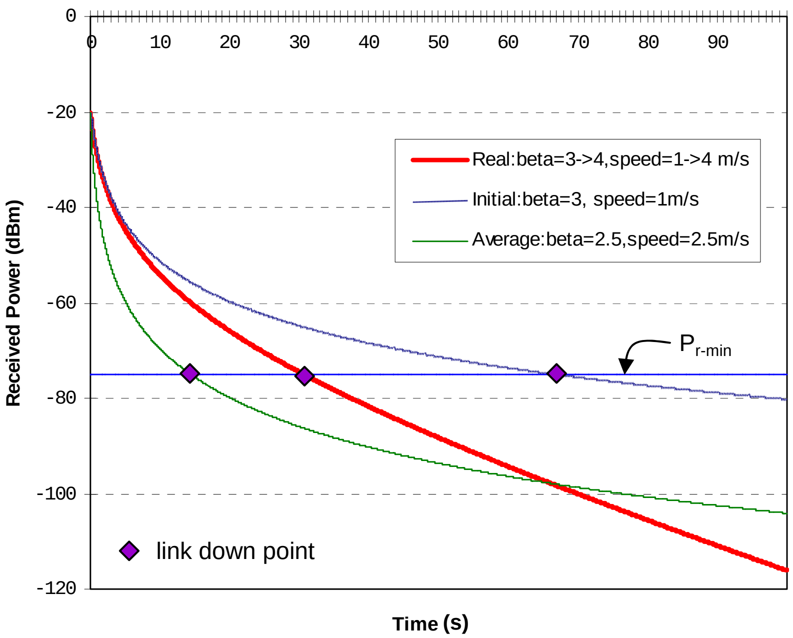
Link event types

- Predictive of events that may occur in the future
  - Link Going Down (LGD)
- Notification of events that have already occurred
  - Link Down (LD)
- To be useful predictive events such as LGD need to occur in time in order to prepare for a handover
- A Link Going Down depends on:
  - Mobile speed that may be variable in time
  - Wireless channel conditions that may be variable in time.

Common issues w/ LGD triggers

- Too late LGD trigger
  - Current link may break before establishing a new link.
  - Longer service disruption time

- Too early LGD trigger
  - Loss of a “working” connection
  - Unnecessary roll-backs or handover cancellations



How to timely generate a LGD trigger considering neighboring networks conditions and dynamic channel characteristics?

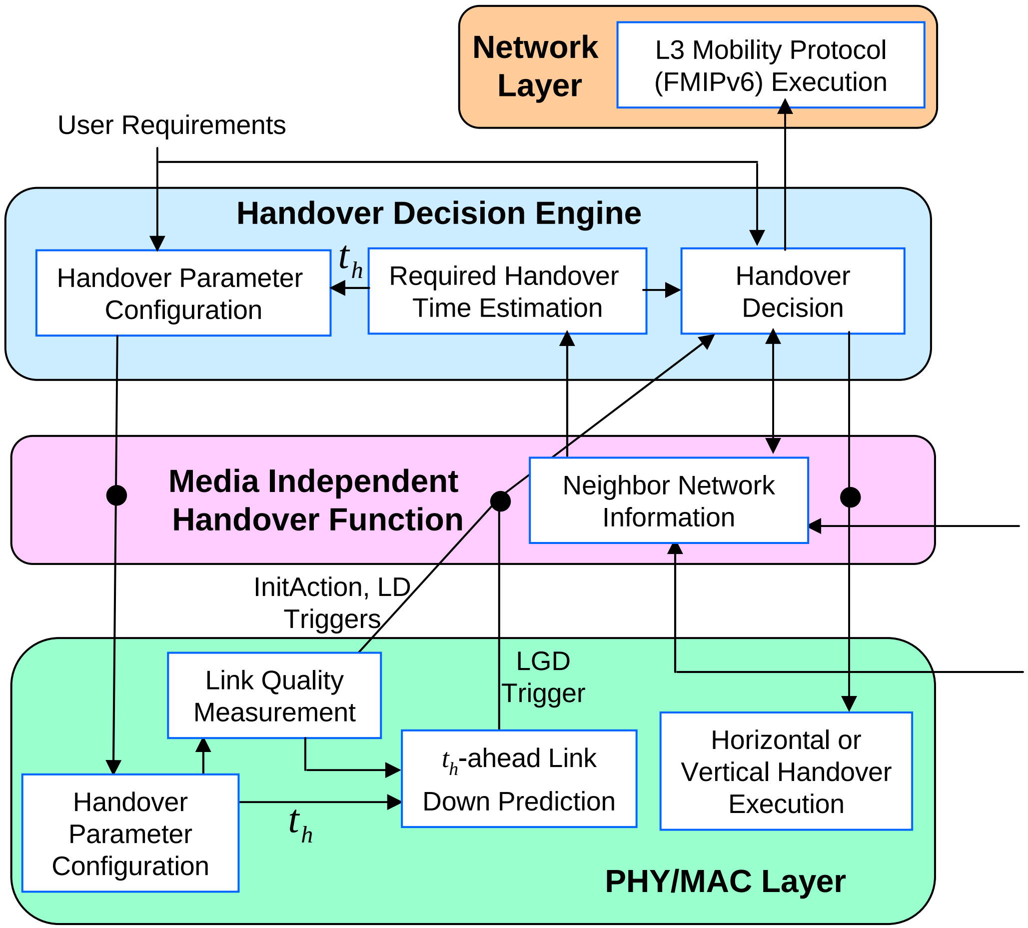
Timely LGD consideration

- An accurate estimate for the time it takes to perform a handover:
  - Neighboring networks topology
  - Single or multiple radio interfaces
  - Layer 3 mobility protocol
  - Handover policy

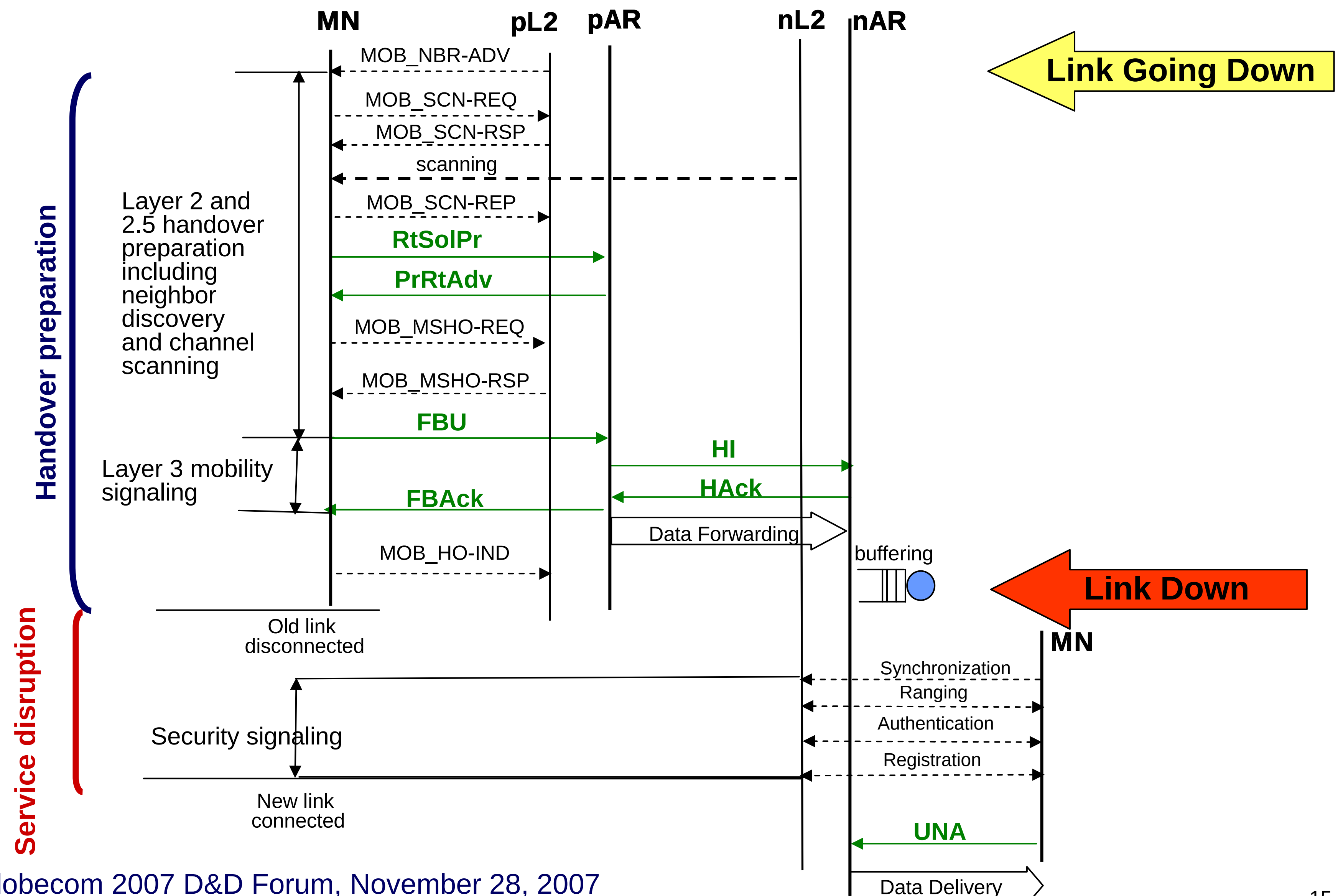
Estimating the handover time

- Many sources of information are available to estimate the handover time
- IEEE 802.21 Media Independent Handover Function
- 802.21 defines primitives and messages to inform the mobile and access nodes of neighboring networks conditions and handover policies.
- If the mobile node knows about neighboring networks and service availability, then it can decide whether to perform a horizontal (same technology) or vertical (different technology) handover.
- Some link layer specifications define native MAC frames to query and respond to neighboring AP (or BS) information queries such as IEEE 802.11k and IEEE 802.16e

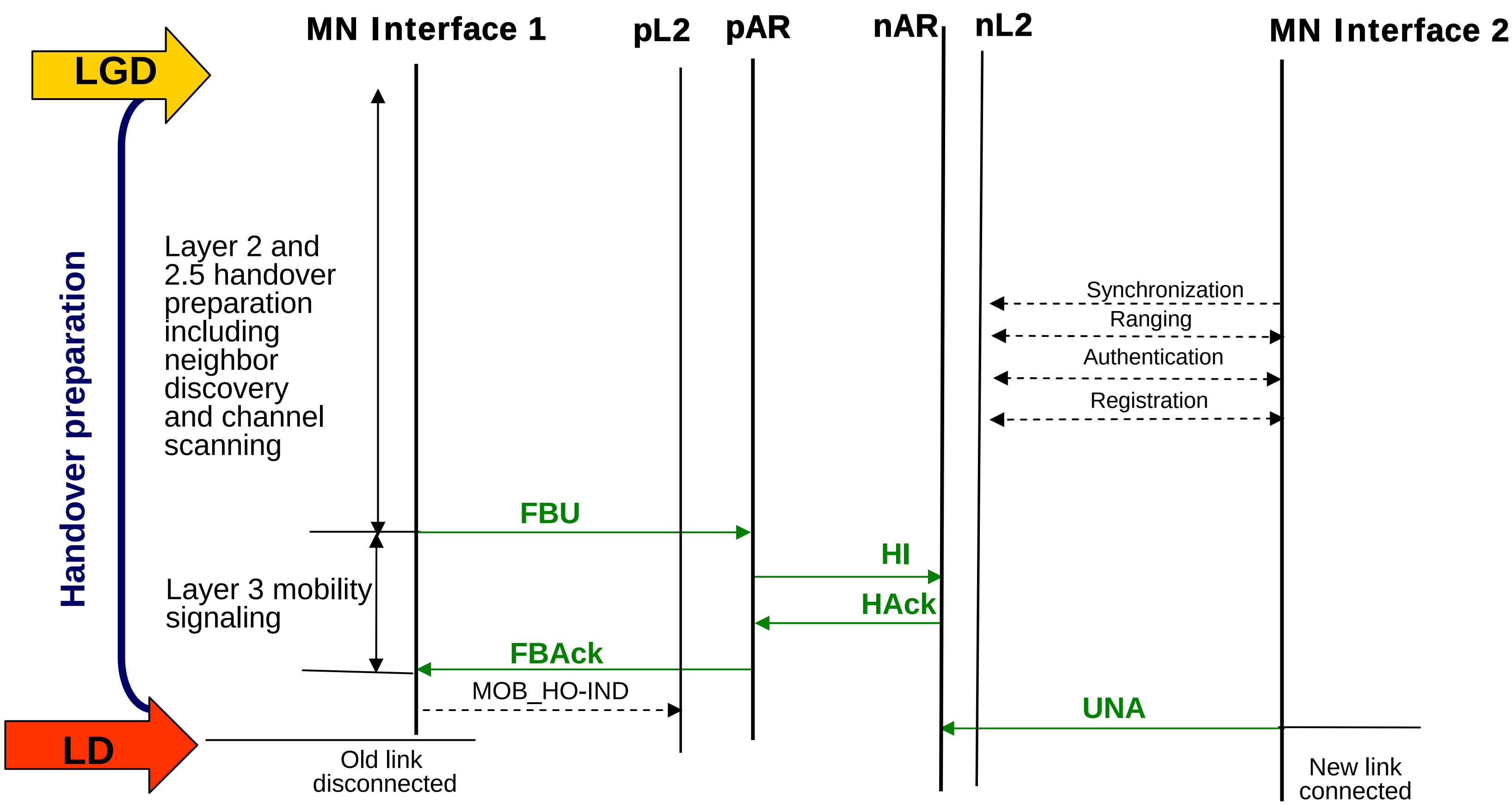
LGD in cross-layer mobility architecture



An example of horizontal handovers



An example of vertical handovers



Example of handover preparation time: WiMAX

No channel found → 20; Channel found → 5; Number of channels → x

Channel scanning (ms)	20*x + 5; 0<=x<256		
Synchronization (ms)	Min=200; Max= 10000		
Ranging (ms)	Min= 5; Max=110		
Registration (ms)	Min=5; Max = 80		
L3 signaling (ms)	40		
Security signaling (ms)	235.42	70.42	10.42
EAP (GPSK) Latency (ms)	226.37	61.37	422.42
	Full Auth	Re-Auth	Indirect Pre-Auth

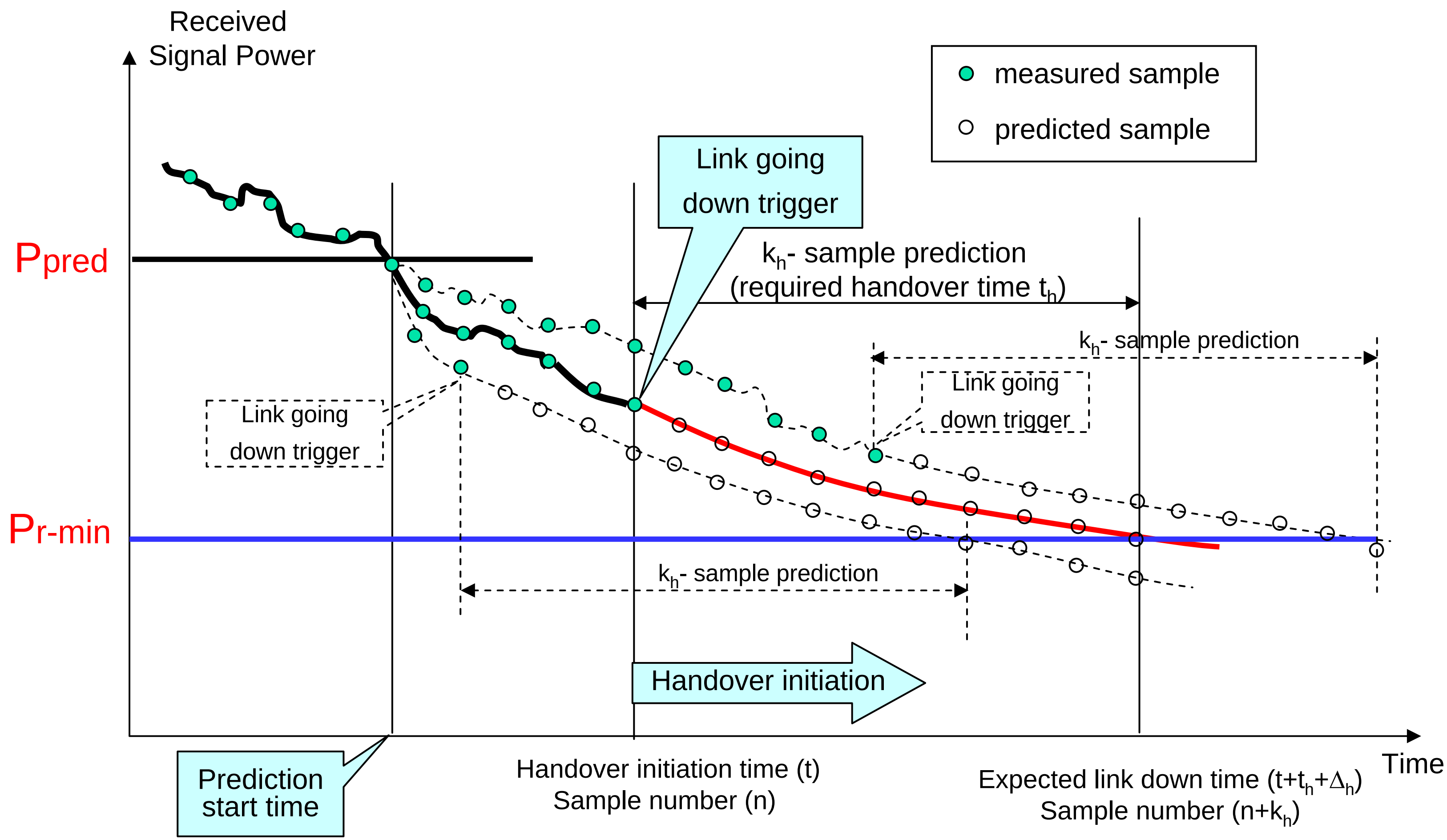
Only used in case of a single radio interface (Indirect Pre-Auth)

Example of handover preparation: WiFi

L3 mobility signaling (ms)	32.5		
Channel scanning (ms)	Min = 60, Max= 260		
Security signaling (ms)	194.33	46.59	3.01
EAP (GPSK) Latency (ms)	192.47	45.07	422.42
	Full Auth	Re-Auth	Indirect Pre-Auth

Only used in case of a single radio interface

Handover trigger and prediction



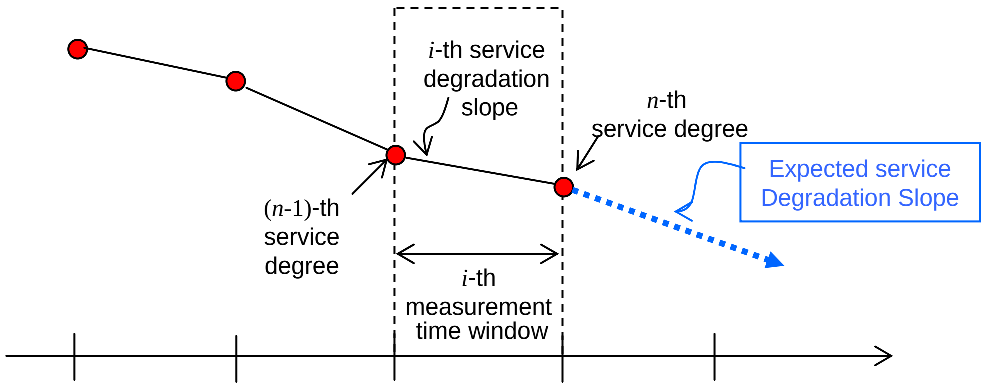
LGD Prediction

- Assume during a short time interval, the service degradation is linear.
- Expected service degradation slope

$$\bar{a}(n) = \eta \cdot s(n) + (1-\eta) \cdot \bar{a}(n-1), \text{ expected service degradation slope}$$

$$s(n) = \frac{x(n) - x(n-1)}{1}$$

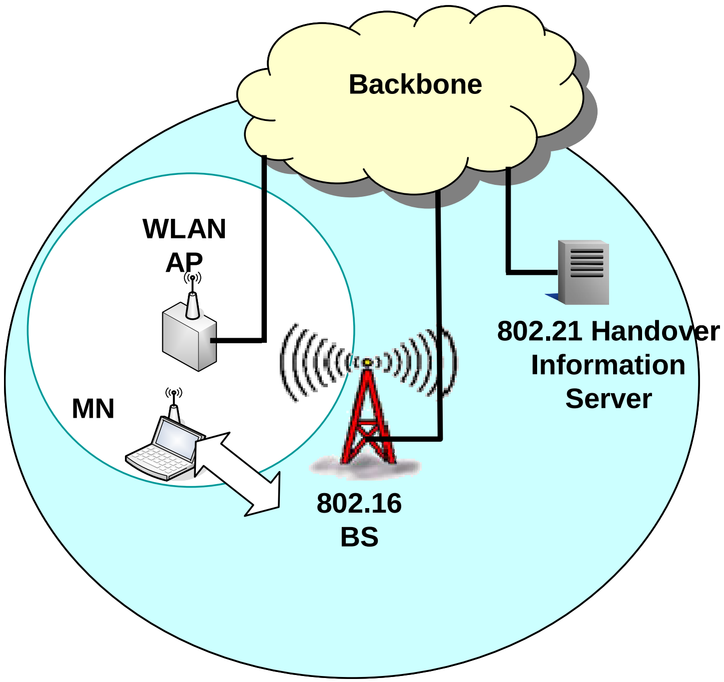
$$\hat{x}(n+k_h) = \bar{a}(n) \cdot k_h + x(n)$$



Numerical results

- C++ implementation
- Parameters

$P_t G_t$	100 mW	d_0	1m
G_r	1	σ	0 – 2dB
λ	0.124 m	$P_{r-\min}$	3.162*10^{-11} W
L	1	β	3 – 4
v	1m/s – 4m/s	t_h	250ms – 500ms
t_s	10 ms	t_m	1ms
Δ_h, Δ_p	0	C_σ	0-4dB
$v_{\max}$	5m/s	$\beta_{\max}$	5
pred order p	10	LMS step μ	0.01



$$P_r(d_0) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_0^2 L}$$

$$\left.\frac{P_r(d)}{P_r(d_0)}\right|_{dB} = -10\beta \log\left(\frac{d}{d_0}\right) + X_\sigma$$

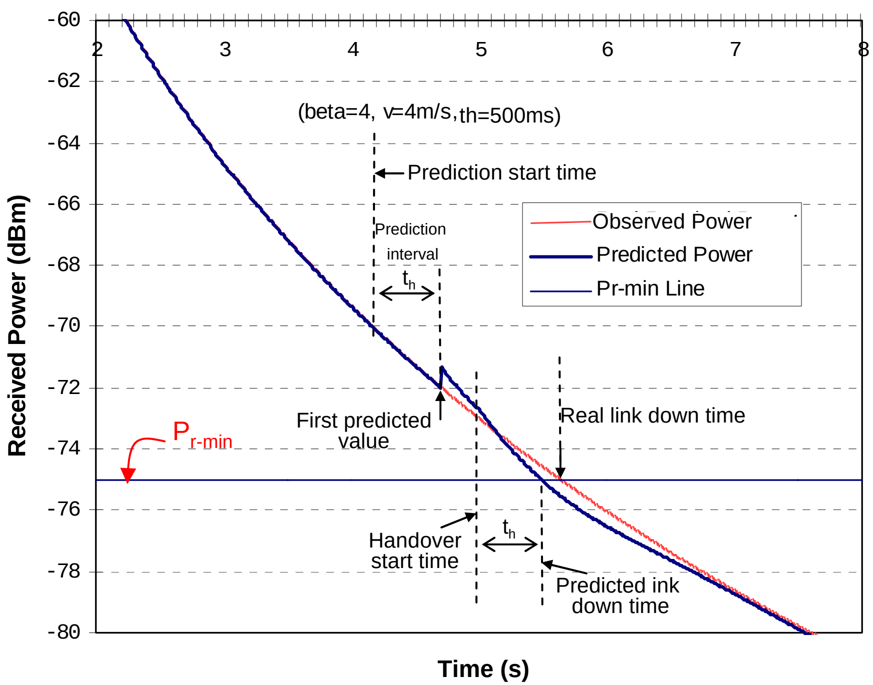
Assume that the actual handover takes the same amount of time with the required handover time that was estimated before the handover execution.

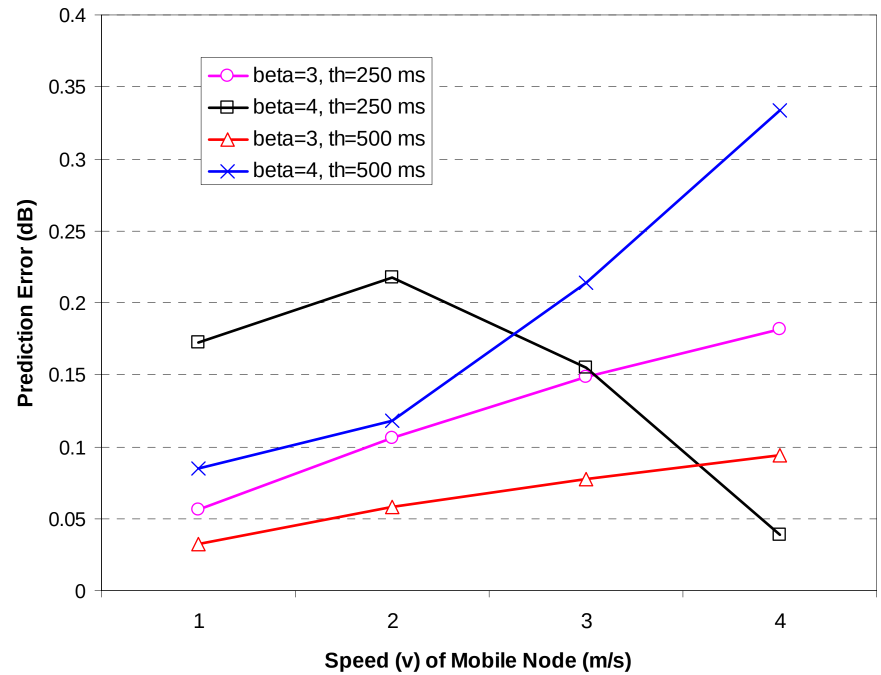
Prediction Error

- Received signal strength prediction error
  - Average prediction error in dB

$$\text{PredError}_{\text{dB}} = \frac{\sum_{i=t_p}^{t_d} \left| \left[\frac{P_r(i)}{\hat{P}_r(i)} \right]_{dB} \right|}{t_d - t_p}$$

- Trends: the larger prediction error for the higher beta and speed (v).
  - Prediction error is very small (max ±0.34dB)





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Prediction performance in estimating the handover time

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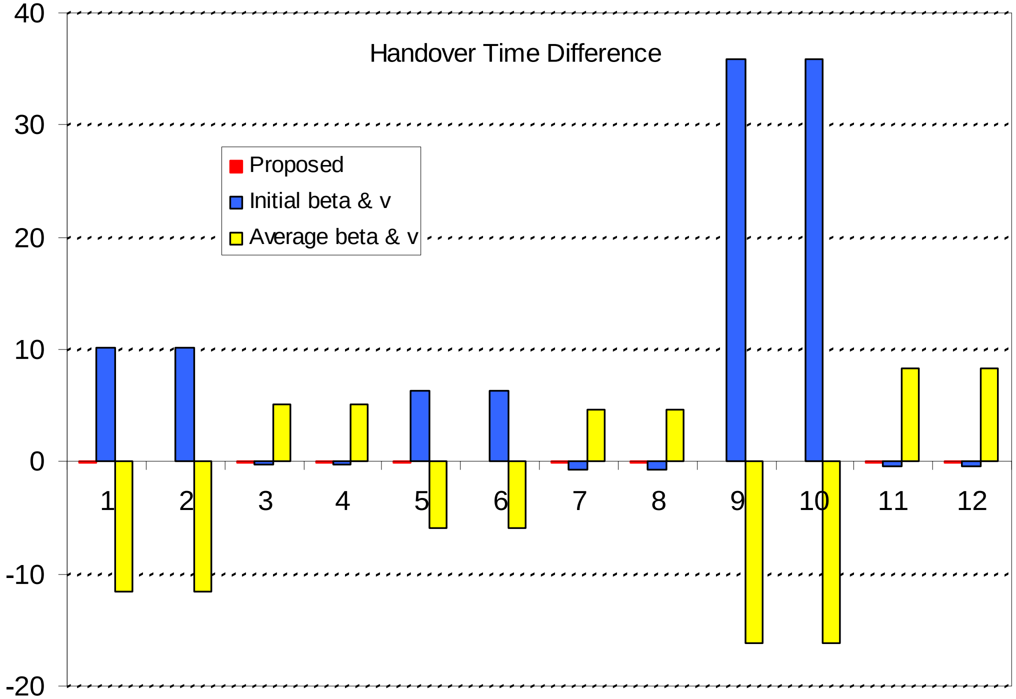
- Handover Time Difference = Handover finish time – link down time
  - Negative Handover Time Difference
    - Handover has finished before the actual link down (desired)
    - Large negative value: perform handover too early (not desired)
  - Positive Handover Time Difference
    - Handover finish time is after the actual link down (not desired)
    - Therefore there is handover disruption and packet losses.
  - Zero Handover Time Difference
- Comparison over proposed scheme with threshold based LGD
  - InitParHo: Handover start time derived from the equation with the initial beta and v values
  - AvgParHo:Handover start time derived from the equation with the average beta and v values
  - In practice, both may not be applicable because we are usually not able to know the initial or average parameter values in advance.



	1	2	3	4	5	6	7	8	9	10	11	12
β start	3.5	3.5	3.5	3.5	3.0	3.0	4.0	4.0	3.0	3.0	4.0	4.0
β final	3.5	3.5	3.5	3.5	4.0	4.0	3.0	3.0	4.0	4.0	3.0	3.0
ν start(m/s)	1	1	4	4	2.5	2.5	2.5	2.5	1.0	1.0	4.0	4.0
ν final (m/s)	4	4	1	1	2.5	2.5	2.5	2.5	4.0	4.0	1.0	1.0
t_h (ms)	250	500	250	500	250	500	250	500	250	500	250	500

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Summary

- Seamless handovers require in addition to *handover policy* cross-layer mobility management:
  - Network monitoring
  - Neighbor discovery
  - Network selection
  - Link event triggers
  - Connection setup
  - Route update
- Timely triggers notify of link events and signal quality
- Cross-layer setting and configuration of link triggers is critical for achieving seamless handovers.

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References

- S.J. Yoo, D. Cypher, and N. Golmie, “Predictive Link Trigger Mechanism for Seamless Handovers in Heterogeneous Handovers,” accepted to appear in Wiley Wireless Communications and Mobile Computing 2008.
- S.J. Yoo, D. Cypher, N. Golmie, “LMS Predictive Link Triggering for seamless handovers in heterogeneous wireless networks,” in the Proceedings of MILCOM 2007, Orlando Florida, October 28-30, 2007.
- A. Izquierdo, K. Hoeper, L. Chen, N. Golmie, “Performance analysis of authentication signaling schemes for media independent handovers, “ IEEE 802.21 Working Group contribution no. 21-07-401.

Useful links

- To obtain a copy of the NS-2 simulation platform visit: http://www.antd.nist.gov/seamlessandsecure/toolsuite.html