Fast Handover Support for Highly Mobile Users using COTS 802.11 Cards

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Abstract

During the November 2008 Plenary, presentations on supporting fast mobile users using 802.11 devices were given and WNG was in favor of hearing follow-up presentations on this subject

This presentations describes a Fast Handover Protocol enabling seamless handover for highly mobile users, e.g. bullet trains.

The system design and proof-of-concept prototype uses COTS 802.11 cards with modified firmware (non-standard compliant MAC).

Empirical performance evaluation show that the handover delay is below 1ms for transmission channel characteristics of a bullet train environment.

Introduction

- IEEE 802.11 WLAN
  - Matured in reliability
  - Available at very low cost

➔ Prevailing to use 802.11 (hardware) components for system designs apart from traditional WLAN
  - Occasionally while giving backward compatibility

- Additional (formerly) untypical application areas:
  - Process-automation, industrial environment
  - Vehicular communication
    - Car-to-car: IEEE 802.11p
    - Telemetry services: Remote-based train control (RBTC)

- Especially for the latter, seamless mobility support is the crucial aspects

- Focus of this talk: System Design and Implementation of Seamless Handover Support enabling RBTC

System Requirements

- Seamless does not mean interruption-free

  The can be black-out time but as seem from the application:
  - Jitter << 10ms
  - Round-trip Delay << 100ms
  - Very seldom (!) loss of a single packet acceptable

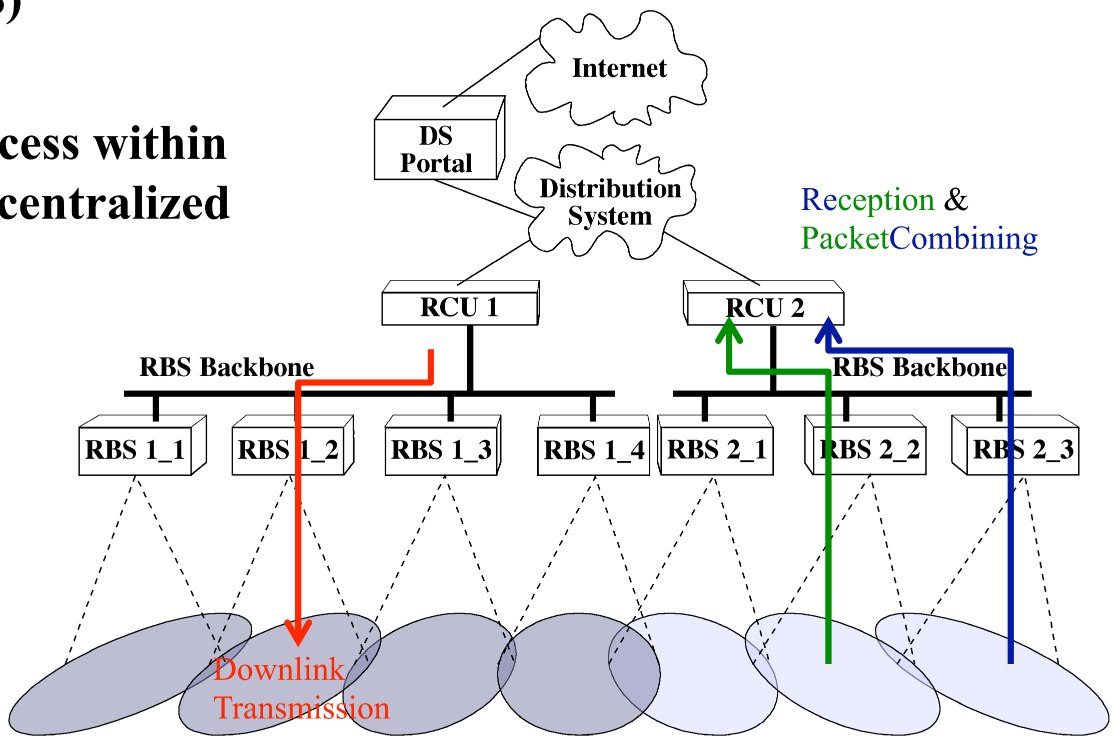
→ Already in the same order of magnitude as 802.11 association needs at most robust rate

- Handover occur very frequently
  - Herein, support velocities up to 600 km/h → handover frequency ≈ 1 Hz
  - Note: this is not an exotic vehicular example
    - Future WLAN system will have a micro cellular architecture (60GH band of IEEE 802.11 VHT)
    - Even moderate pedestrian velocities can cause handover at the same frequency as a fighter jet flying down the Broadway
- Use of commercial off-the-shelf equipment
  - IEEE 802.11 chipsets / cards
  - Compatibility with legacy devices not an issue
    → modified firmware possible
- Only one network interface card at the mobile (redundant NICs for safety only)
- Guranteed QoS even under high load

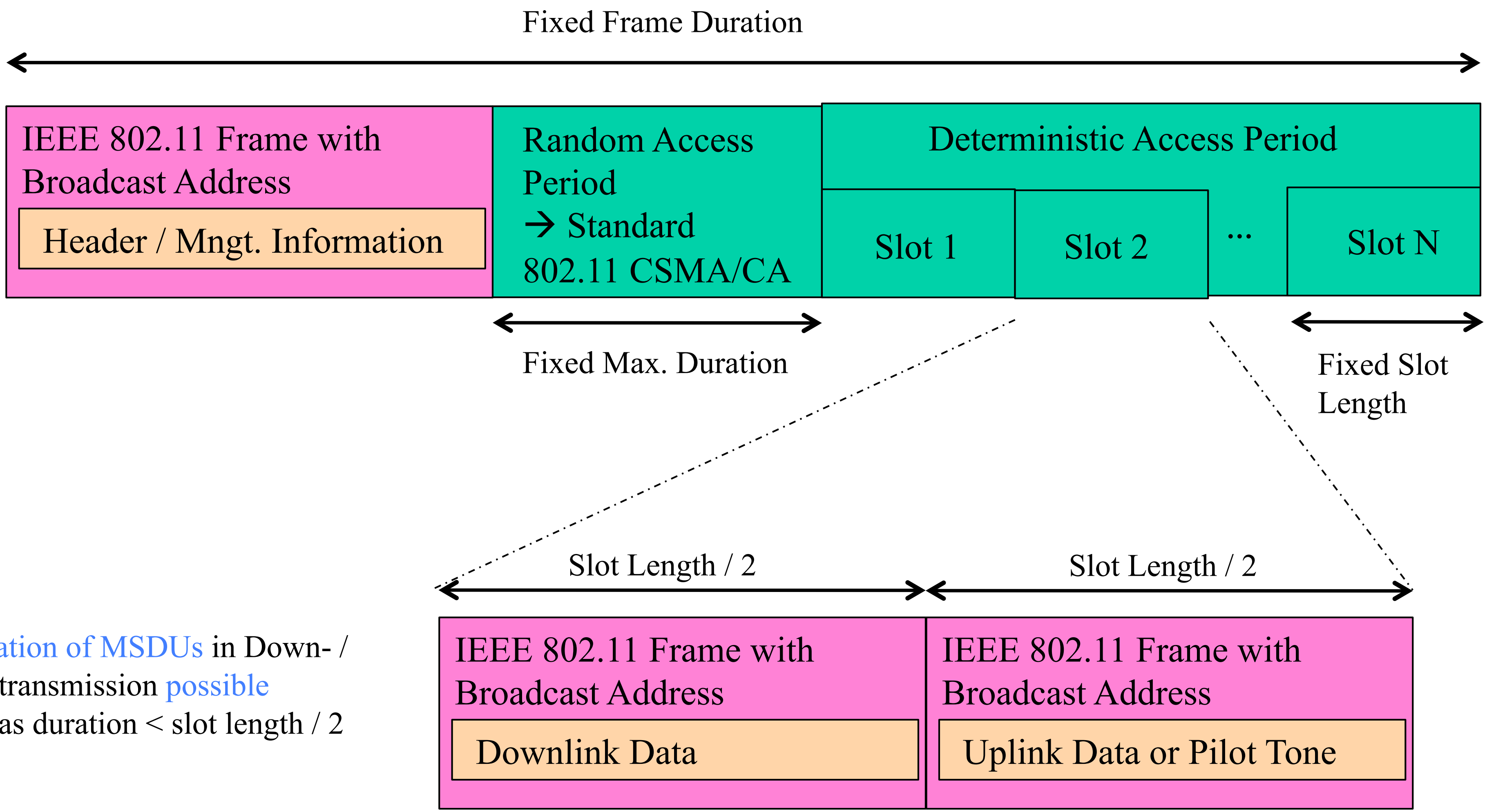
System Architecture

Design principle: avoid handover (as seem be the mobile) as often as possible
→ Micro- / macro-cellular system

- **Micro cells operate on same, adjacent macro cells on different frequencies**
- **Micro cells physically formed by spatially distributed Remote Based Stations (RBS)**
- **Interference free medium access within a macro cell imposed by the centralized Radio Control Unit (RCU)**
- **Data is transmitted via a single RBS BUT can be received via several RBSs → packet combining at RCU possible**



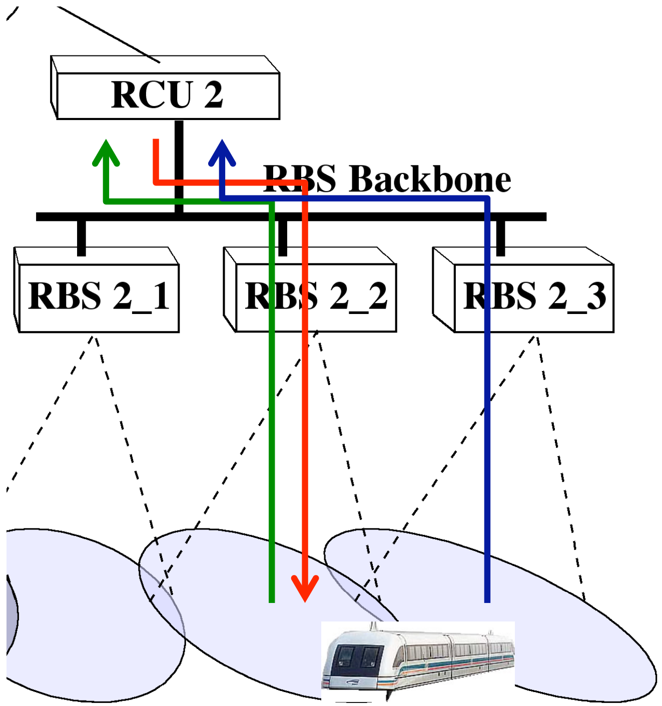
MAC Scheme



Aggregation of MSDUs in Down- / Uplink-transmission possible as long as duration < slot length / 2

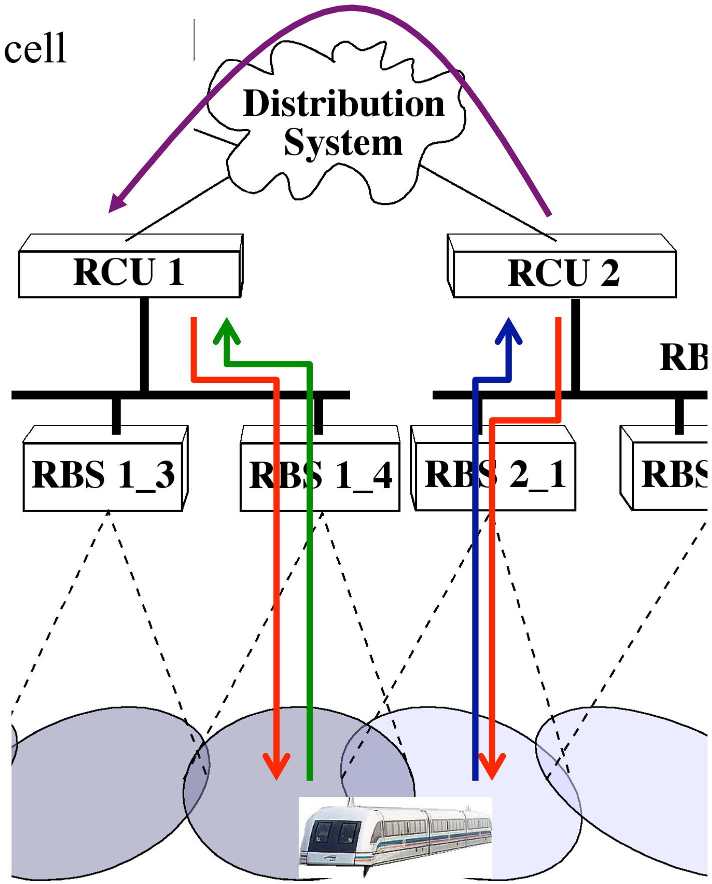
Fast Handover – Intra-Macro-Cell

- **Remember: All RBSs receive the transmission and forward it to the RCU <-> mobile in overlap, handover immediate**
- **Mobile always has an uplink transmission (data or pilot)**
- **RCU**
  - Can inherently track the mobile's position
  - Has knowledge on channel characteristics as observed by the involved RBSs
  - Can decide based on RSSI which RBS to use for the next downlink transmission <-> use low pass filter to compensate for short term fading



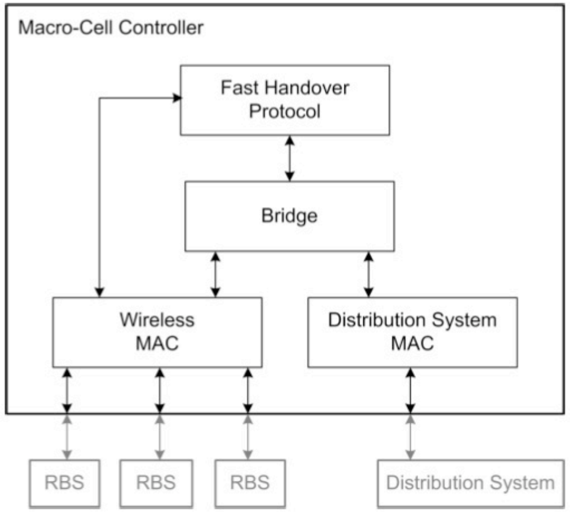
Fast Handover – Inter-Macro-Cell

- **RCU**
  - detects that mobile enters the boundary of the macro cell
  - signal to neighbor RCU via DS that handover might be inherent
  - signals to mobile frequency of neighboring macro cell
- **Neighbor RCU**
  - allocates down- and up-link resources and
  - predicatively starts transmitting downlink data
- **Mobile**
  - decides based on RSSI to conduct a handover, i.e. switch to the frequency of neighbor macro cell
  - immediately receives downlink traffic and may transmit uplink data



PROOF-OF-CONCEPT DEMONSTRATOR & PERFORMANCE EVALUATION

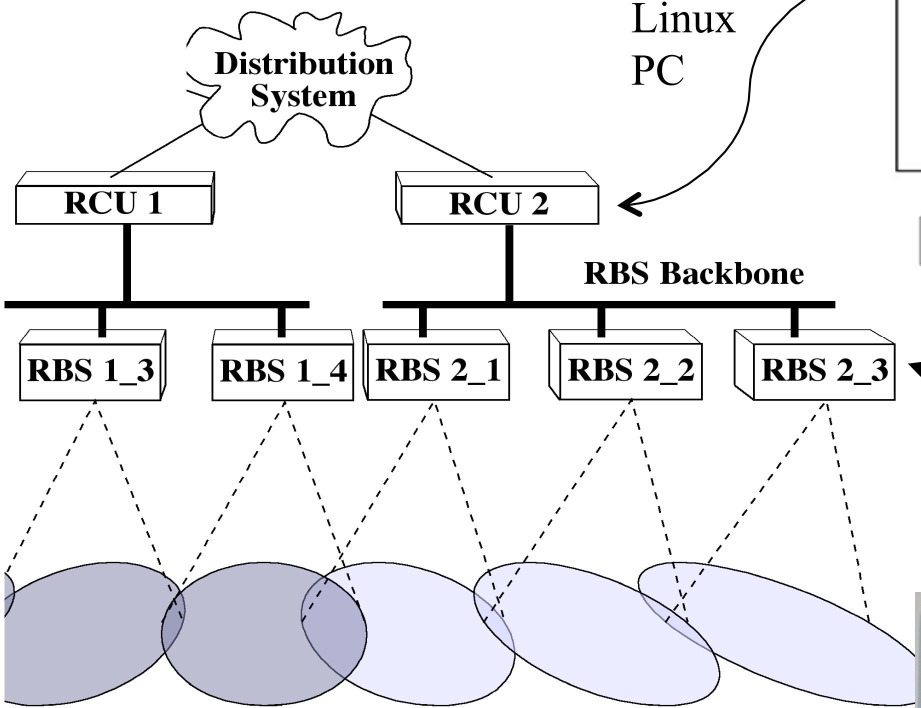
Implementation: Architecture Components



Specification of all components in SDL

Automated Code generation for run time system (Linux PC or 802.11 card)

Standard Linux PC

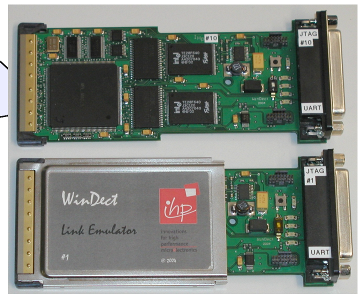


802.11 Prototyping Card

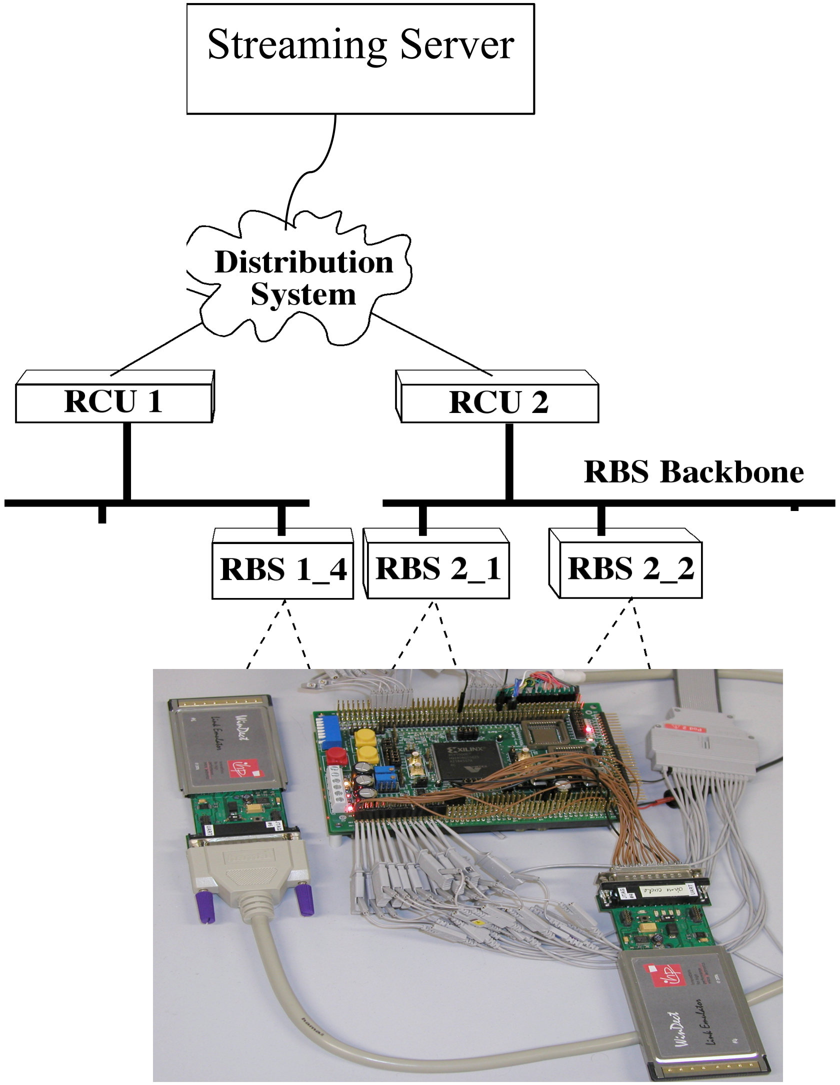
a) either directly connected to RCU (PC Card slot)

or

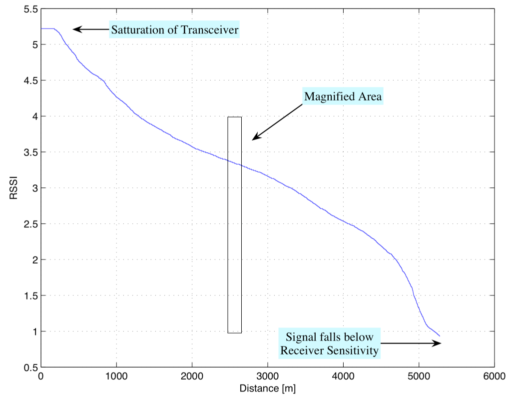
b) placed within a 2nd standard Linux PC and connected via UPD/IP tunnel

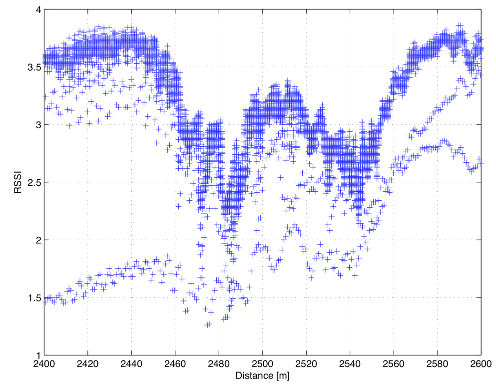


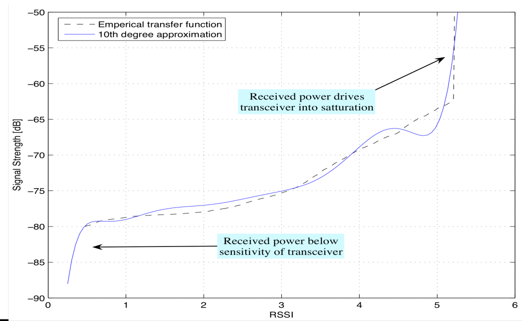
Experiment Set-Up



- Only four MAC prototyping cards
→ Allows Intra- and Inter-Macro-Cell Handover
- MAC boards connected via FPGA-based channel emulator
- Attenuation changed according to channel traces
- Required conversion RSSI → dB according to transceiver characteristic





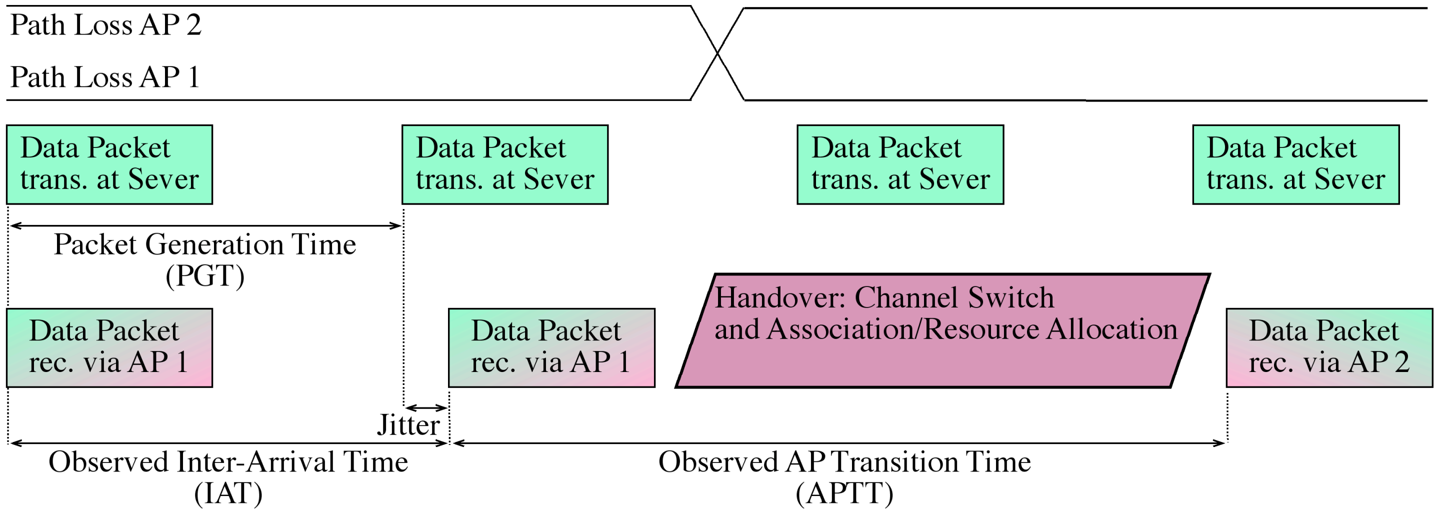


Access Point Transition Time Metric

Access Point Transition Time (according to IEEE 802.11.2):

Time between last successfully received (user) packet from the old AP and first successfully received (user) packet from the new AP

→ Includes all signaling / management overhead



Handover Delay:

$$HOD := E\{APTT\} - E\{IAT\}$$

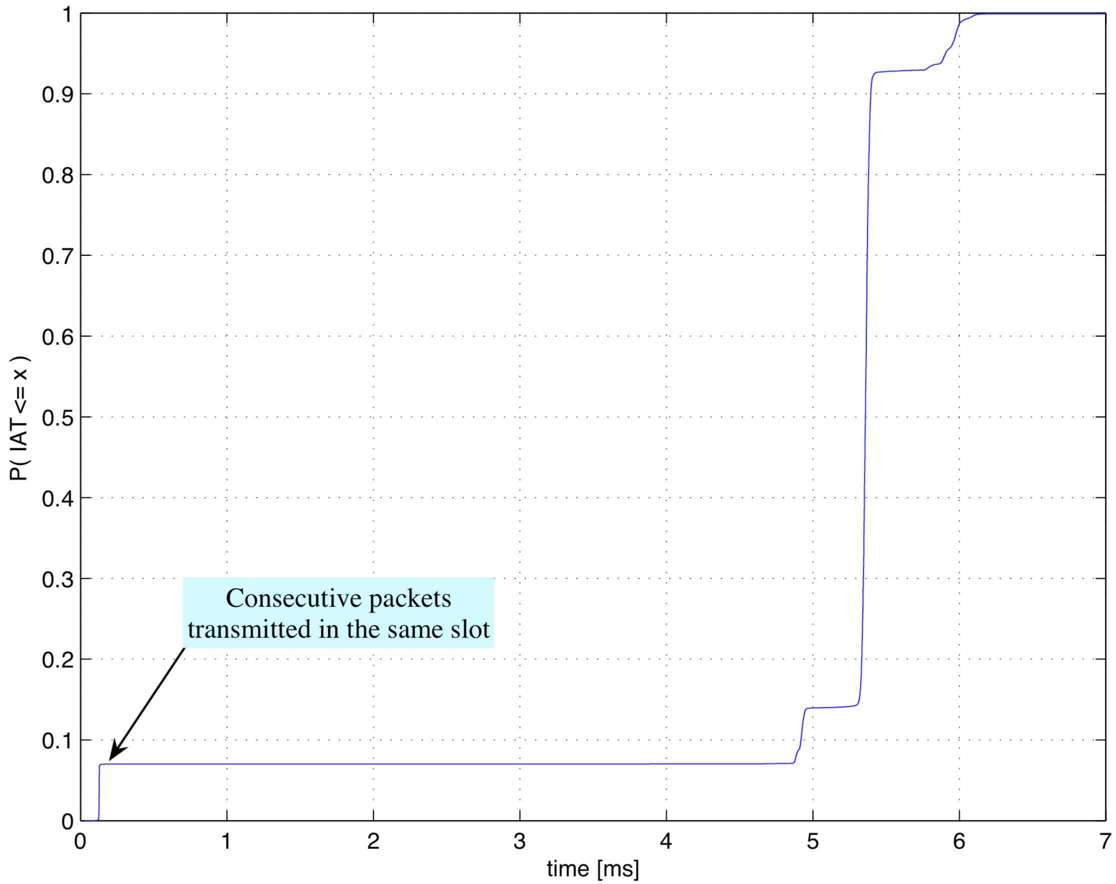
Three Scenarios

Configure channel emulator to restrict user mobility

- (1) within one micro cell (no handover)
- (2) within one macro cell (intra-macro-cell handover)
- (3) within all macro cell (intra- and inter-cell handover)

➔ **Clearly distinguish between effects coming from the implementation and from the behavior of the handover protocol**

CDF of Inter-Arrival Times (No handover)

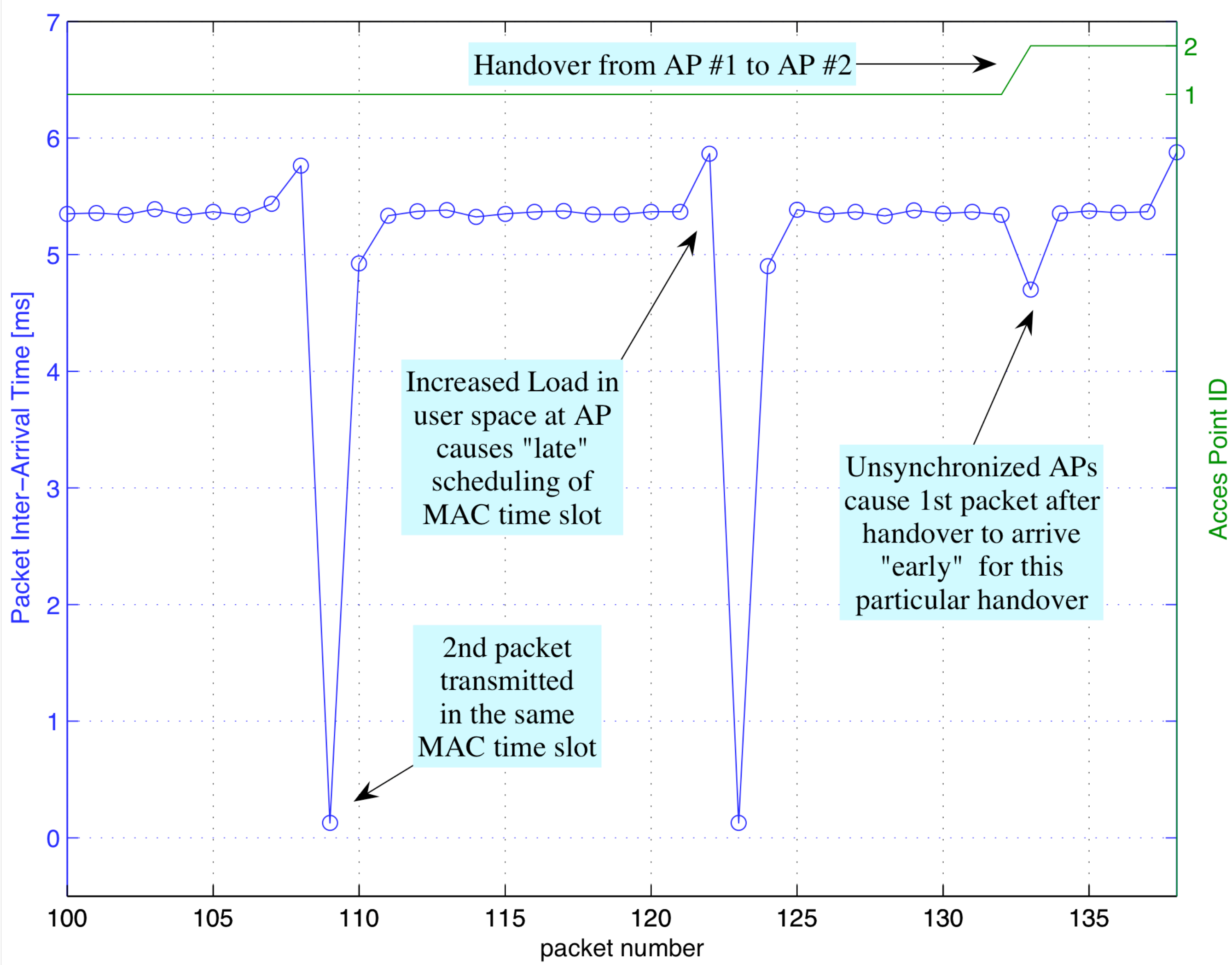


Packets transmitted every 5ms

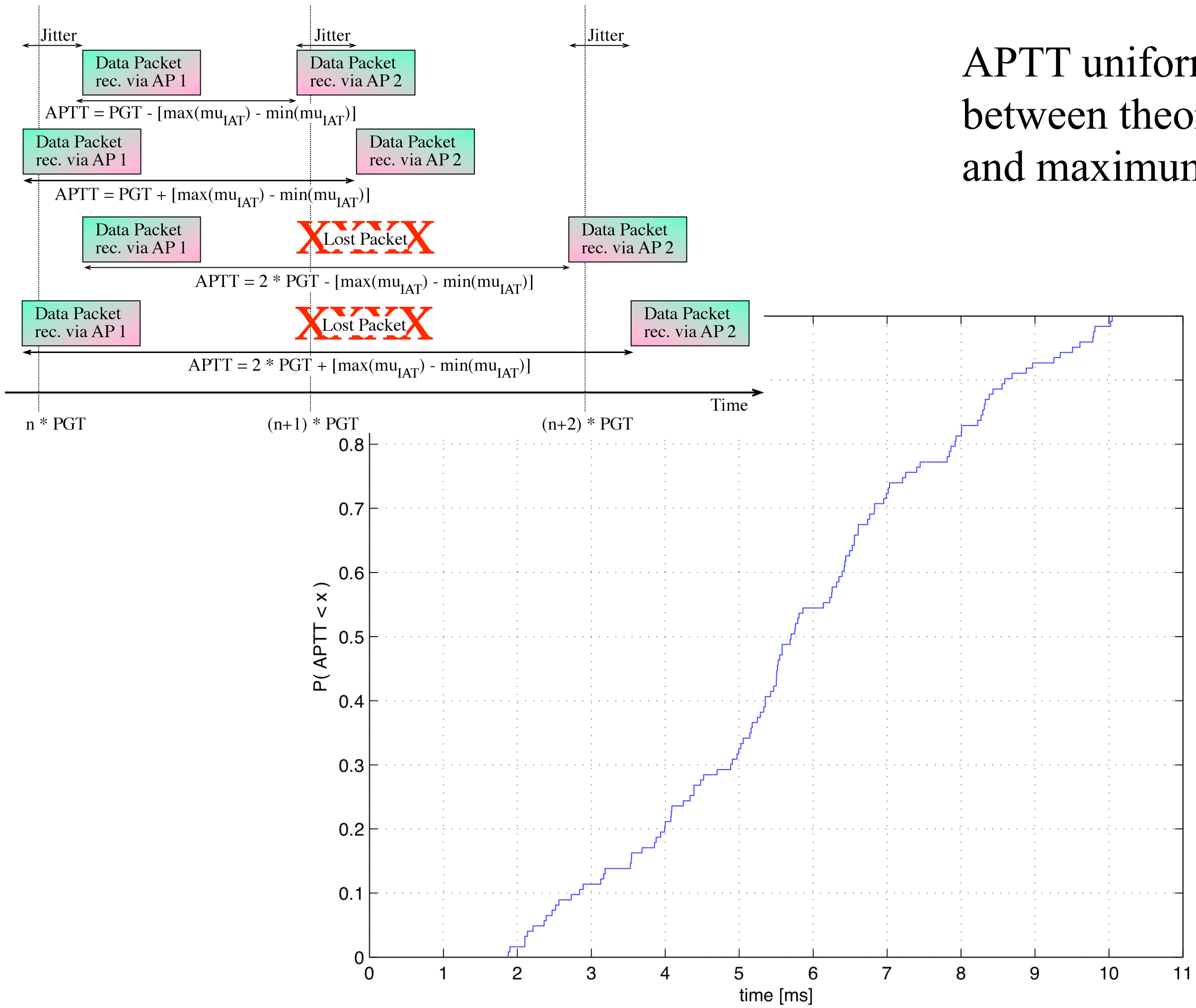
Average IAT: 5.01 ms

Good news: CDF exactly the same if mobile moves within a macro cell

Packet Inter-Arrival Times (Snapshot)



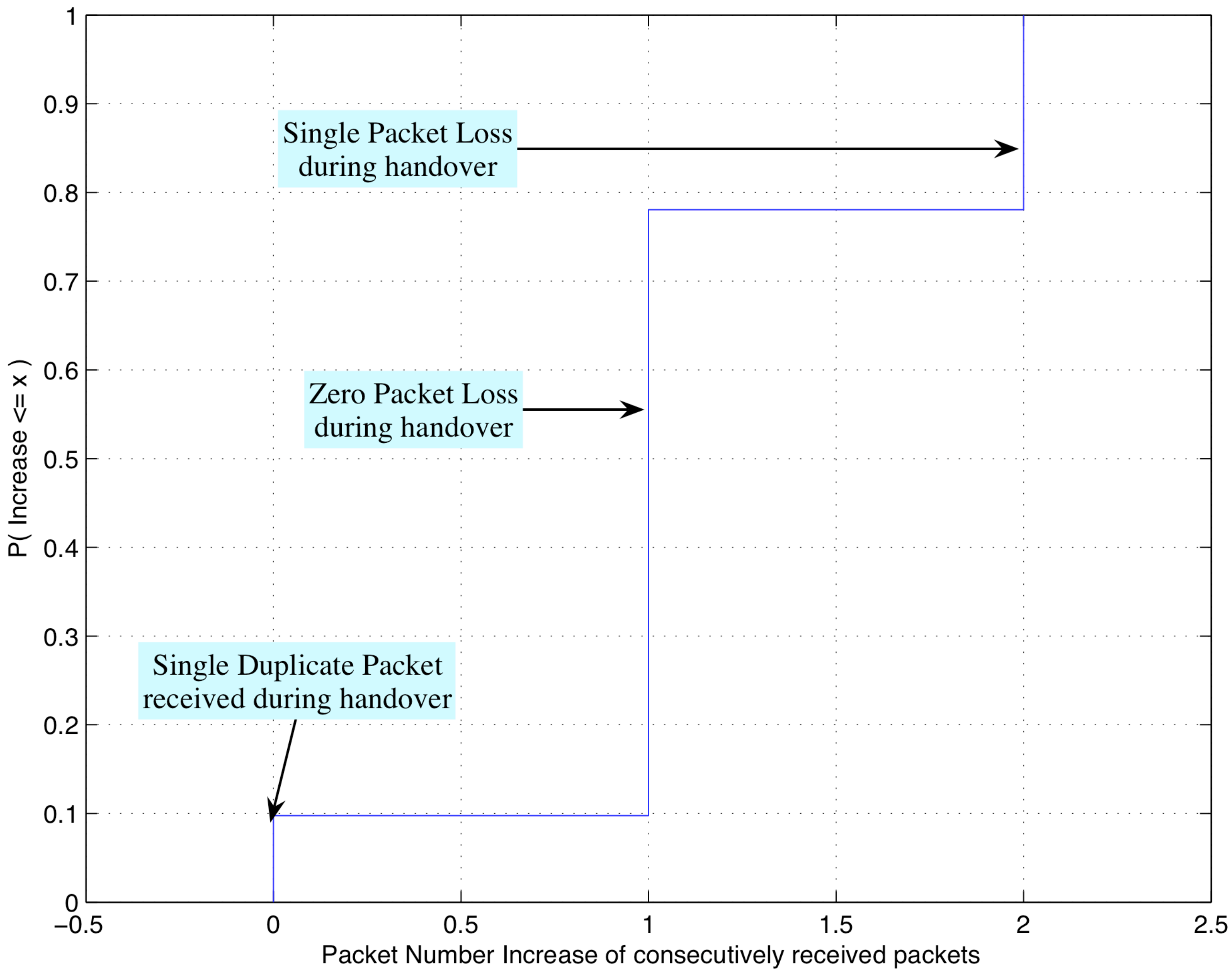
CDF of Access Point Transition Time



APTT uniformly distributed between theoretical minimum and maximum

HOD = E{APTT} – E{IAT}
= (5.84 – 5.37) ms
= 0.47 ms

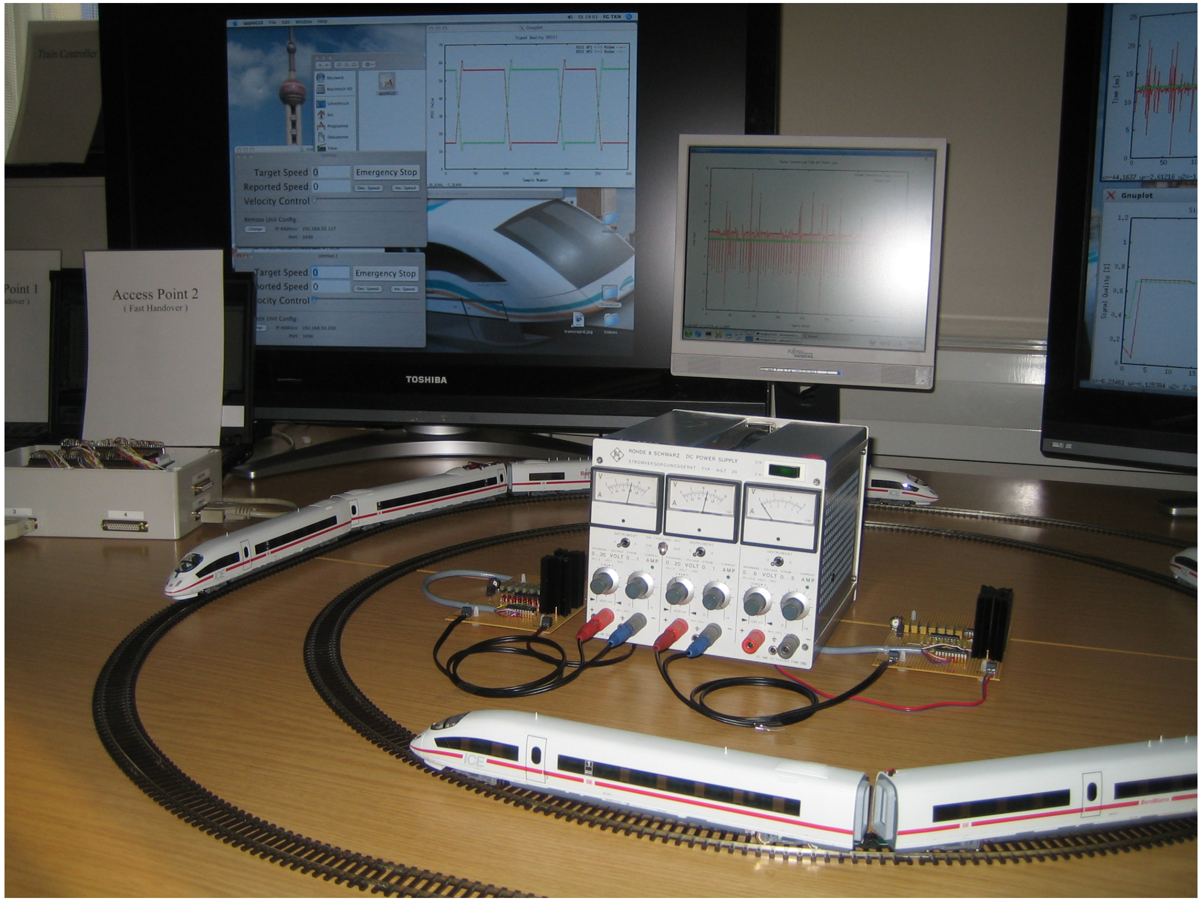
Packet-Loss during Inter-Cell Handover



Conclusion

- **Fast and seamless handover for Real-Time Telemetry is possible using standard COTS IEEE 802.11 chipsets**
- **Performance evaluation**
  - Based on a proof-of-concept prototype implementation employing channel traces of a high speed train
  - Using metrics conformant to the IEEE recommended practice for wireless performance prediction
  - Show that the average handover delay << 0.5 ms
  - Empirical access point transition time confirms analytical upper and lower bound

Our Bullet-Train Prototype



References

- **M. Emmelmann, T. Langgärtner, and M. Sonnemann. System Design and Implementation of Seamless Handover Support Enabling Real-Time Telemetry Applications for Highly Mobile Users. In Proc. ACM International Symposium on Mobility Management and Wireless Access (MobiWac 2008), Vancouver, Canada, October 2008, pp. 1-8, ISBN 978-1-60558-055-5. (pdf)**

- **Marc Emmelmann. Influence of Velocity on the Handover Delay associated with a Radio-Signal-Measurement-based Handover Decision. In Proc. of IEEE Vehicular Technology Conference (VTC 2005 Fall), Dallas, TX, USA, September 2005. (PDF)**

- **11-05/0233r1 – Marc Emmelmann. Velocity Effects on RSM-based Handover Decision**

- **11-08/1273r1 – Sangwoo Lee et al. Hybrid MAC for MANET.**

- **11-08/1337r0 – Hitoshi Morioka. Broadband Access for High Speed Transportation**

Straw Poll

- **Are you further interested in presentations on how to support mobility for highly mobile user?**

- **Yes: 22**
- **No: 0**
- **Abstain: 7**