Enabling Gigabit Services for IEEE 802.11ad-Capable High-Speed Train Networks

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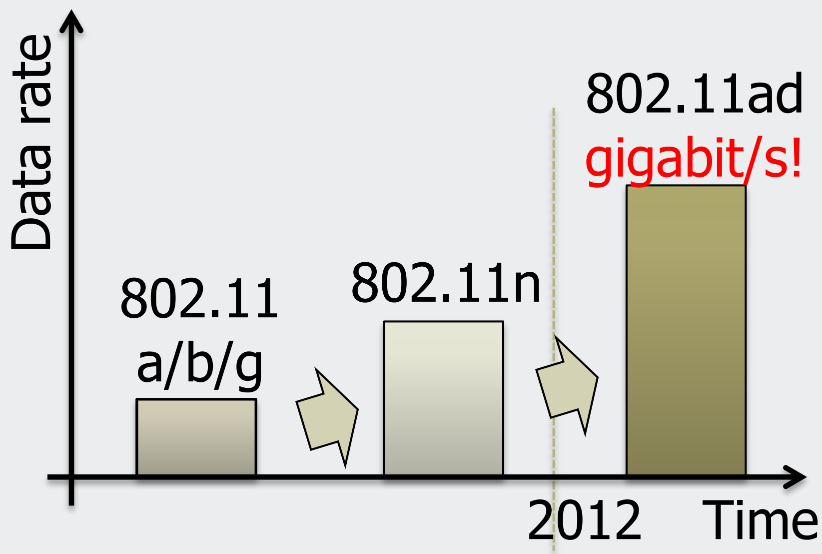
January 22, 2013

Outline

- Introduction
- A Reference Network Architecture
  - Link Budget Analysis
  - Architecture Descriptions
- Proposed Scheme
- Simulation Results
- Conclusion and Q&A

Introduction

WLAN Evolution



Multi-Gigabit WLAN with
a 60 GHz Channel

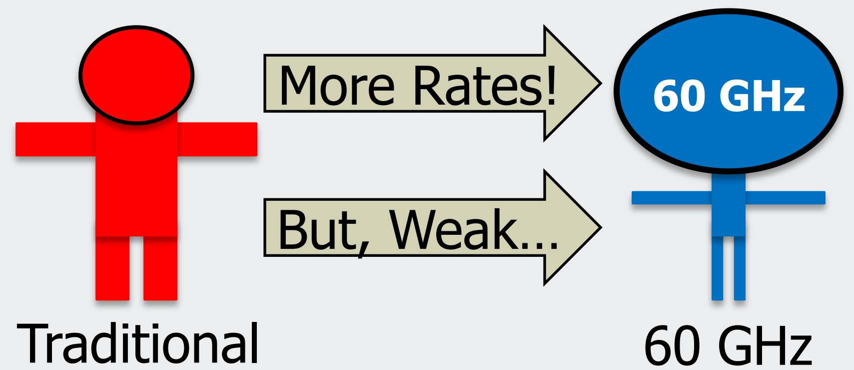
Challenges in 60 GHz

Friis Path Loss Model:

$$\boxed{P_{RX}} = \frac{G_{TX} G_{RX} c^2}{(4\pi d)^2 \boxed{f_c^{\,2}}} P_{TX}$$

12^2 times weaker than 5 GHz signals

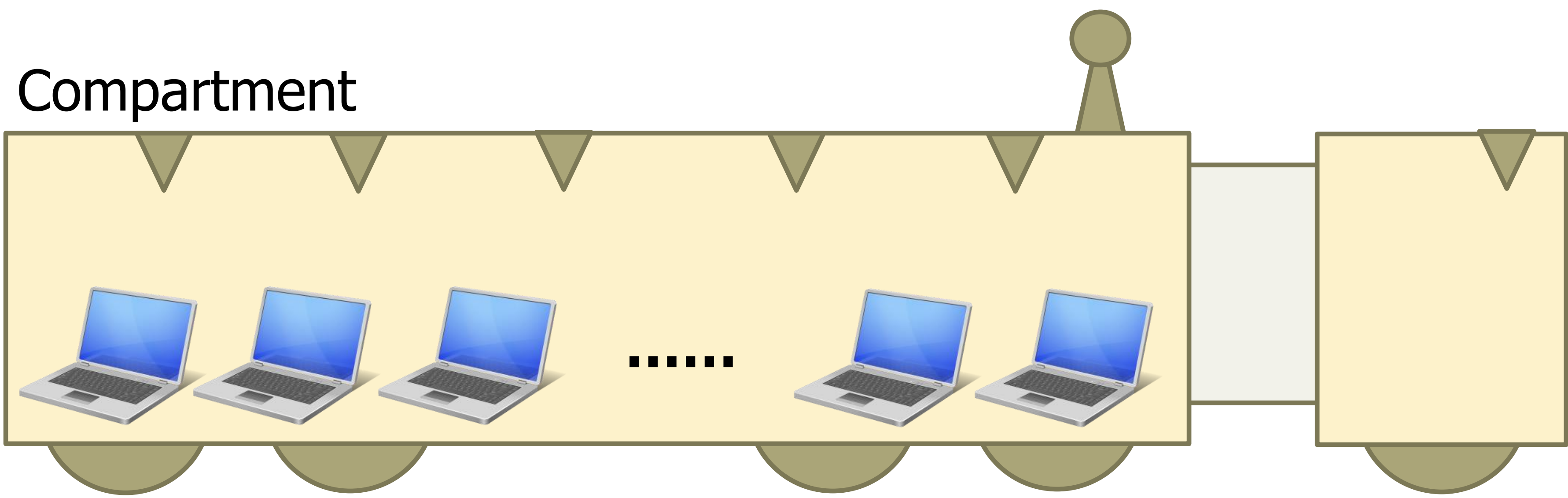
$(60G/5G)^2 = 12^2$ times higher than 5 GHz signals



Introduction

- High-Speed Train Applications
  - Motivation
    - The sum-rate requirements from a train compartment can easily reach gigabit/s

Compartment



Introduction

- High-Speed Train Applications
  - Differences from the traditional 802.11ad applications
    - It is operating outdoors, over much larger distances
    - It has to deal with velocities that are two orders of magnitude higher
    - It does not encounter non-line-of-sight situations

Introduction

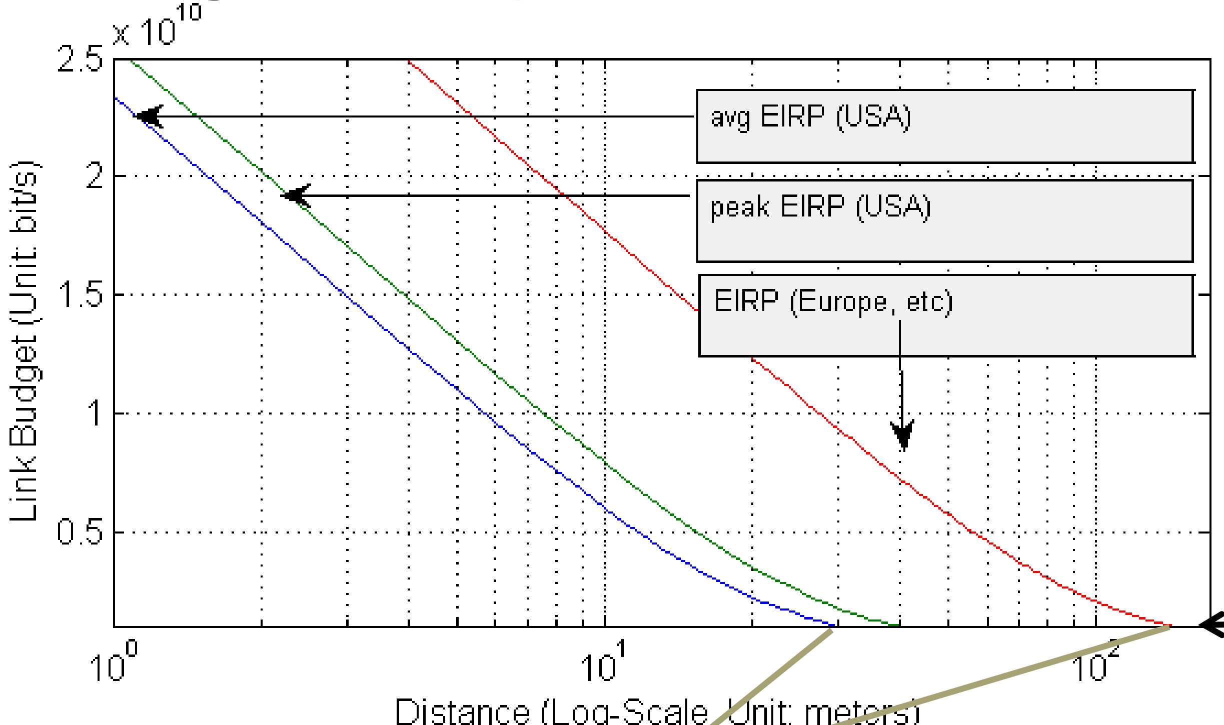
- Our Approach
  - **Investigating the Link Budget:**
    - Determining the maximum distances that infrastructure base stations (BSs) are allowed to be placed apart.
  - **Formulating the Optimization Framework:**
    - Since we assume that each compartment has its own transmission/reception antenna, we investigate the optimum pairing of BS antennas and sectors with train antennas.
    - We formulate the optimization problem, which has to be solved frequently due to the rapid train movement.

A Reference Network Architecture

- A Reference Network Architecture
  - Link Budget Analysis
  - Architecture Descriptions

A Reference Network Architecture

- Link Budget Analysis

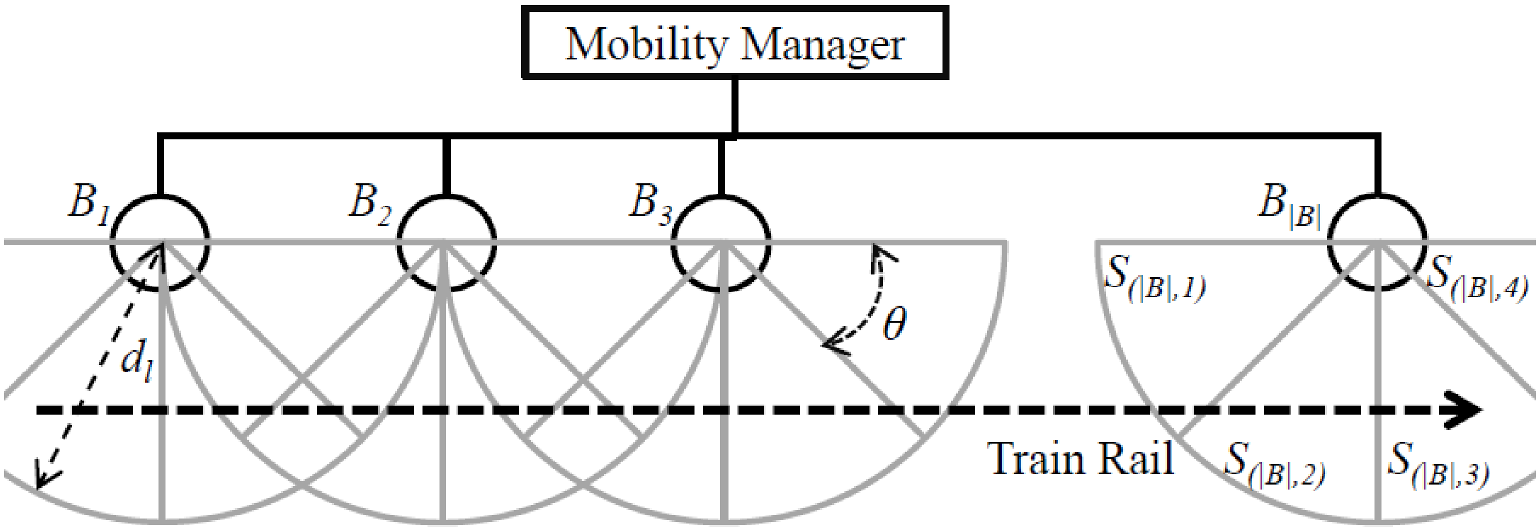


$\leftarrow 0.1 \cdot 10^{10}$

Gigabit/s data rates can be achievable up to 30m (USA) or 150m (Europe)

A Reference Network Architecture

- Architecture Descriptions



  - All BSs are connected to MM (mobility manager).
  - Each BS has 802.11ad capable RF and covers its sectorized areas.

Proposed Scheme

- Optimum Pairing and Sector Assignment
  - Assumption
    - We know the capacity for all the links and sector combinations between infrastructure and train.
    - There is one antenna per one compartment.
  - Solution Approach
    - MM computes the optimal matching between BSs and the multiple antennas on the train.
    - Objective: **sum-rate maximization**

Proposed Scheme

- Optimum Pairing and Sector Assignment
  - Optimization Framework

Function for the date rates from B_j to C_i

$$\max \sum_{i=1}^{|C|} \sum_{j=1}^{|B|} \boxed{\mathcal{L}(B_j \rightarrow C_i)} \cdot \boxed{\mathcal{I}(B_j \rightarrow C_i)}$$

Boolean index for indicating the connection

$$
\begin{aligned}
s.t. \quad & \sum_{i \in \mathcal{T}_p} \mathcal{L}(B_j \rightarrow C_i) && \geq && \mathcal{G}, \forall k, \forall j \\
& \sum_{i=1}^{|C|} \mathcal{I}(B_j \rightarrow C_i) && \leq && 1, \forall j \\
& \sum_{j=1}^{|B|} \mathcal{I}(B_j \rightarrow C_i) && \leq && 1, \forall i
\end{aligned}
$$

Proposed Scheme

- Optimum Pairing and Sector Assignment
  - Optimization Framework

$$\max \sum_{i=1}^{|C|} \sum_{j=1}^{|B|} \mathcal{L}\left(B_j \rightarrow C_i\right) \cdot \mathcal{I}\left(B_j \rightarrow C_i\right)$$

$$s.t. \quad \sum_{i \in \mathcal{T}_p} \mathcal{L}\left(B_j \rightarrow C_i\right) \geq \mathcal{G}, \forall k, \forall j$$

$$\sum_{i=1}^{|C|} \mathcal{I}\left(B_j \rightarrow C_i\right) \leq 1, \forall j$$

$$\sum_{j=1}^{|B|} \mathcal{I}\left(B_j \rightarrow C_i\right) \leq 1, \forall i$$

Each BS sector can be associated with at most one compartment sector and vice versa

Proposed Scheme

- Optimum Pairing and Sector Assignment
  - Optimization Framework

$$\max \sum_{i=1}^{|C|} \sum_{j=1}^{|B|} \mathcal{L}\left(B_j \to C_i\right) \cdot \mathcal{I}\left(B_j \to C_i\right)$$

$$\text{s.t.} \quad \boxed{\sum_{i \in \mathcal{T}_p} \mathcal{L}\left(B_j \to C_i\right) \geq \mathcal{G}, \forall k, \forall j}$$

$$\sum_{i=1}^{|C|} \mathcal{I}\left(B_j \to C_i\right) \leq 1, \forall j$$

$$\sum_{j=1}^{|B|} \mathcal{I}\left(B_j \to C_i\right) \leq 1, \forall i$$

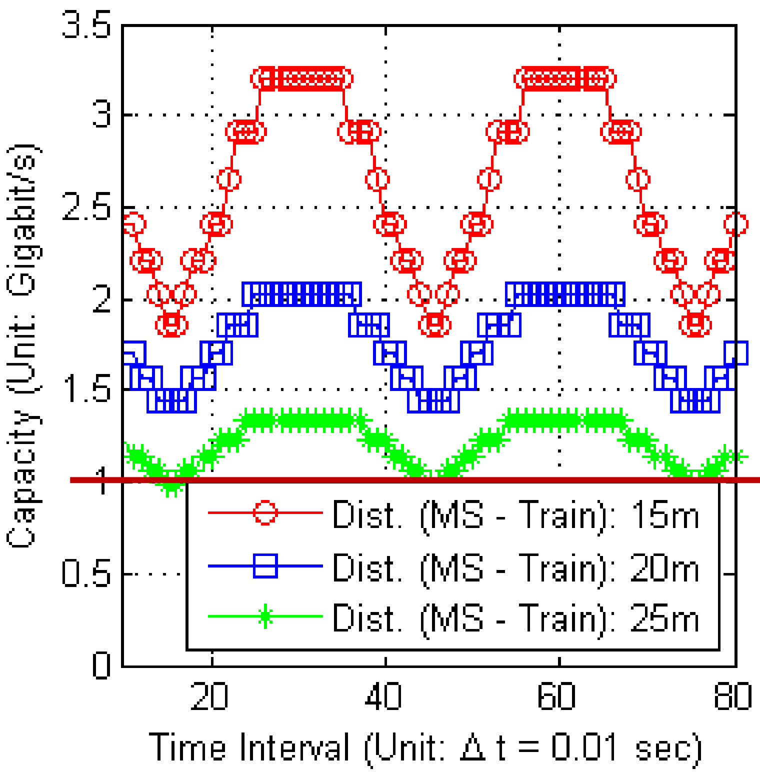
Data rate of every compartment (i.e., summed over the compartment sectors) should be more than *G* which ensures a minimum (compartment) transmission rate

Simulation Results

- Setting and Assumptions
  - The speed of train: 360 km/h
  - The standard deviation of the estimation velocity error: 3.6
  - The BSs and compartments are aligned.
  - The distances between BSs: 30m
  - The distances between compartments: 30m

Simulation Results

- Simulation Results

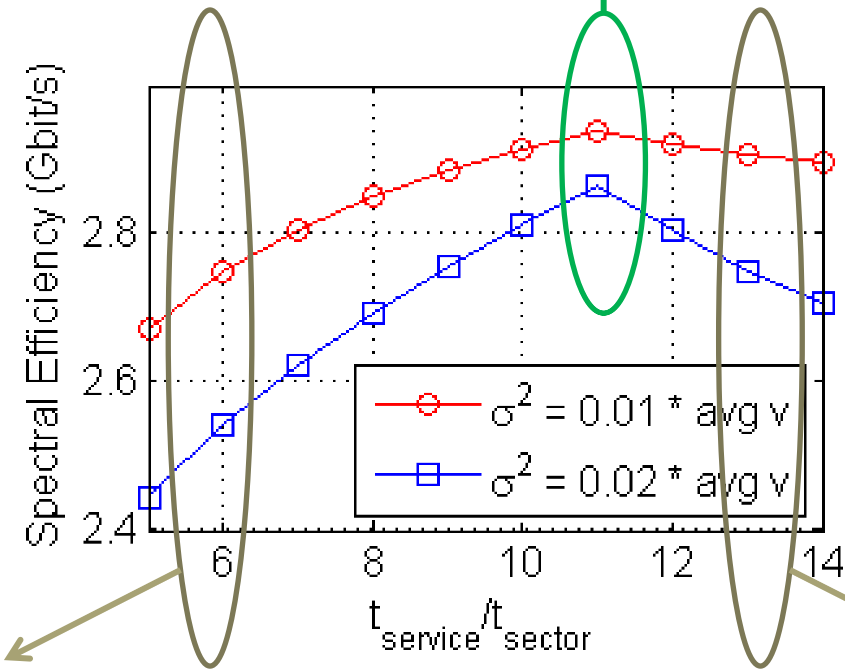


The achieved capacity per compartment exceeds
1 gigabit/s when
the distance between BS and compartment is less than 25m.

Simulation Results

- Simulation Results

Optimum (depending on the velocity error).



•**For small ratios,**

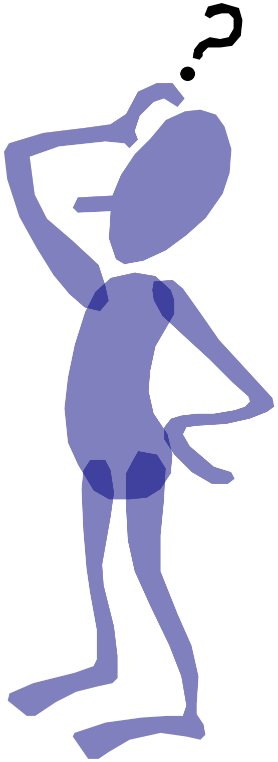
• The sector sweeping overhead leads to a small spectral efficiency.

•**For large ratios,**

•The error in the position estimate results in wrong sector assignments.

Conclusion and Q&A

- Conclusion
  - An optimization framework is proposed for supporting gigabit/s mobile services in high-speed train networks.



- Q&A?