Next Generation Mobile Communications for High-Speed Railway





Prof. Bo Ai

Beijing Jiaotong University

Outline

- Development of HSR in the World
- Dedicated Mobile Commu. for Rail
- Hot Topics

Development of HSR in the World







- France:
- Japan:
- Spain:
- Germany:
- China:

… … …

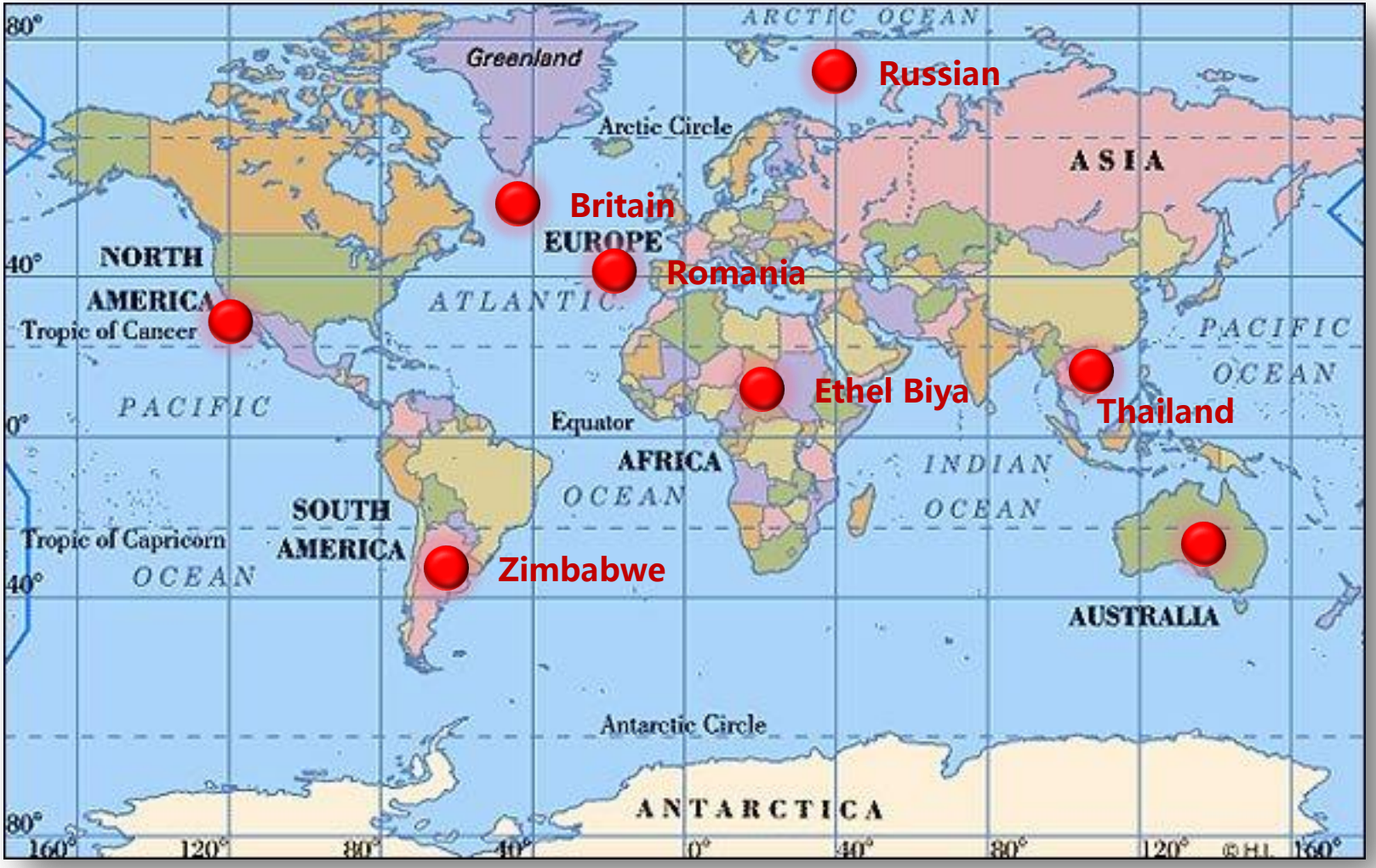


Development of HSR in the World

Year 2013

Country	Kilometers	Operation Speeds
China	11028	300
Japan	2681	320
Spain	2665	300
France	2531	320
Germany	1401	300
Italy	986	300
Korea	426	300
England	113	300

Development of HSR in the World



Development of HSR in the World



Distance: 800 miles

Average Speed: 220 km/h

Travel time: 2 hours 38 mins

Estimated Costs:

- **HST: $55.00**
- **Air: $120.00**
- **Car: $86.00**

Development of HSR in the World

- **High mobility, Safety, Punctuality, Comfort**





- **3 minutes tracking intervals @ 350 km/h-400 km/h**

Outline

- Development of HSR in the World
- **Dedicated Mobile Commu. for Rail**
- Hot Topics

Dedicated Mobile Commu. for Rail



In 2009, *Smart Railway*



In 2012, *Future Railway Development*

IEEE Standard for
Local and metropolitan area networks—

Part 15.4: Low-Rate Wireless Personal Area Networks (WPANs)

Amendment X: Positive Train Control (PTC) System Physical Layer

In 2013



In 2014, Horizon 2020——*Shift2Rail*



In 2015, *HRRC* Group

Dedicated Mobile Commu. for Rail

Guest Editorial Broadband Wireless Communications for High Speed Vehicles

The 15 papers in this special issue are divided into four categories: challenges in broadband wireless communications; physical layer techniques; radio resource management techniques; and field measurement and channel modeling.

Published in:
Selected Areas in Communications, IEEE Journal on (Volume:30 , Issue: 4)

Page(s):
673 - 674

ISSN :
0733-8716

DOI:
10.1109/JSAC.2012.1200501

Date of Publication :
May 2012

Date of Current Version :
12 四月 2012

Issue Date :
May 2012

Publisher:
IEEE

Dedicated Mobile Commu. for Rail

IEEE Communications MAGAZINE

CALL FOR PAPERS

Future Railway Communications

Intelligent transportation systems (ITS) are a growing part of modern life. Some of the goals of ITS are efficiency, environmental friendliness (being "green"), and of course, safety. The scope of ITS is broad, and all transportation modes will require communications. This includes future vehicular (automotive) systems and vehicle-to-vehicle/vehicle-to-infrastructure (V2V/V2I) communications, aeronautical communications, maritime communications, satellite communications, railway communications, and possibly others. Integration between these modes of communication will also be required.

The growing use of railways for both passenger and freight transportation has yet to attract sufficient attention in the literature. With numerous high-speed rail systems being used and planned in China and Europe in particular, reliable communications for both railway control/safety, and passenger applications, are of great current and future interest. In addition to safety and reliability, high efficiency, environment friendliness, and passenger convenience are also goals of future railway development. This feature topic will focus on the key communication technologies for future railway communication systems.

- Railway passenger communication systems
- Internet of things for railways
- Train-to-train communication technologies
- Social network applications for railways
- Fifth-Generation communication technologies for railways
- Green communication technologies for railways

SUBMISSION GUIDELINES

Prospective authors should follow the *IEEE Communications Magazine* manuscript format described in the Authors Guidelines at **http://www.comsoc.org/commag/paper-submission-guidelines**. Articles should be tutorial in nature and should not exceed 4500 words. Note that equations are generally not permitted; exceptions to this rule, allowing up to three equations, may be made with permission of the editor. All articles to be considered for publication must be submitted through the IEEE Manuscript Central (**http://mc.manuscriptcentral.com/commag-ieee**), according to the following timetable:

IMPORTANT DATES

- **Manuscript Submission Deadline:** April 1, 2015
- **Decision Notification:** June 1, 2015
- **Final Manuscript Deadline:** August 1, 2015
- **Publication Date:** October 2015

Submit articles to the "October 2015/Future Railway Communications" category.

Dedicated Mobile Commu. for Rail

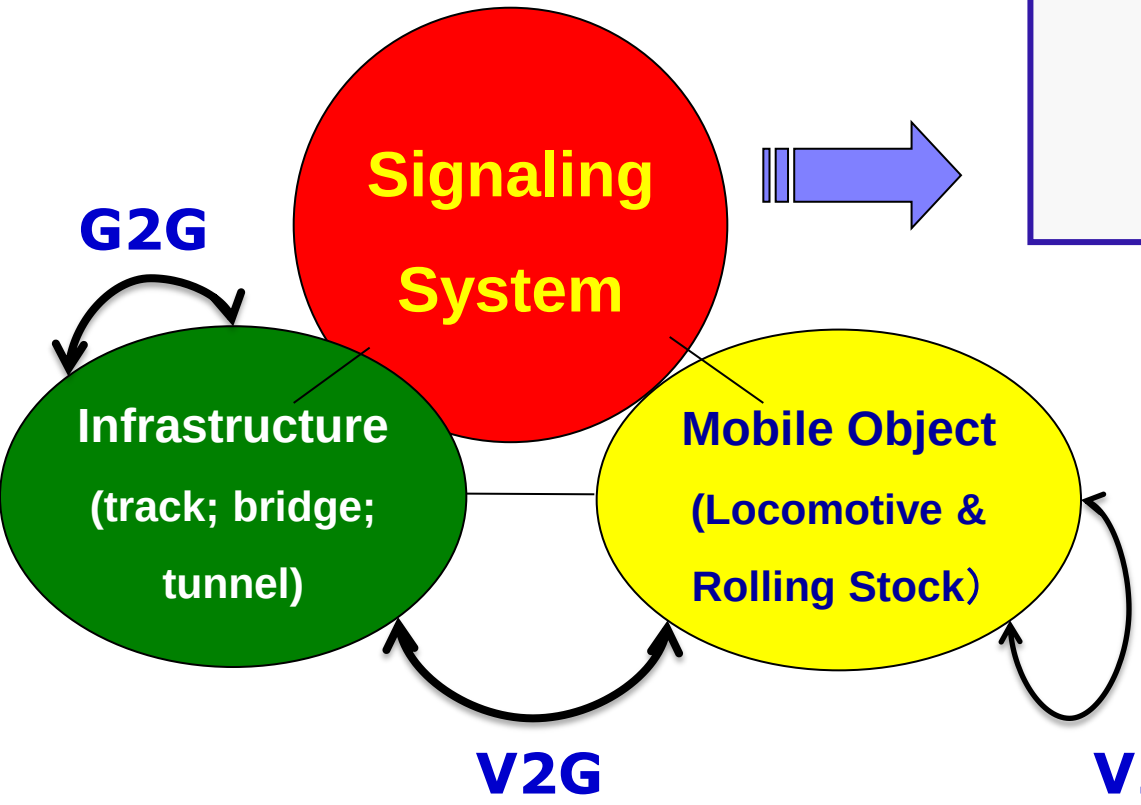
Public Land Mobile Communications

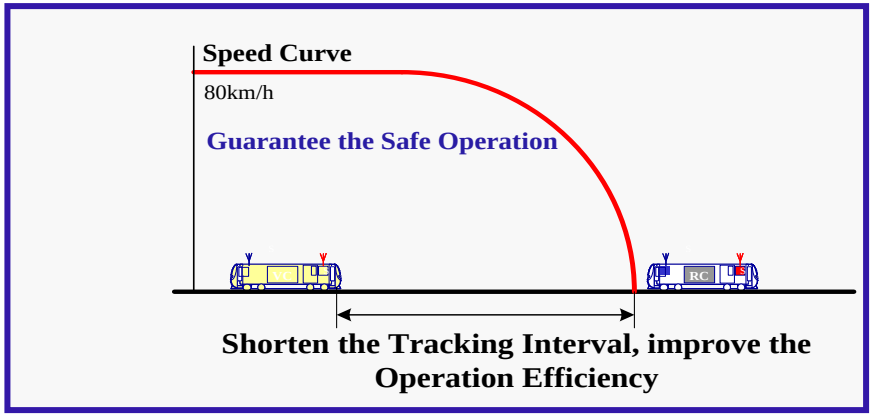
?

Dedicated Mobile Communications for Railways

Dedicated Mobile Commu. for Rail

Fundamental Components of HSR







Dedicated Mobile Commu. for Rail

Signaling System (Train Operation and Control System)

- ETCS: European Train Control System
- CTCS: Chinese Train Control System
- CBTC: Communication Based Train Control System

Positive Train Control (PTC) IEEE 802.15 Task 4p

Dedicated Mobile Commu. for Rail

IEEE 802.15-4p

IEEE Standard for
Local and metropolitan area networks—

Part 15.4: Low-Rate Wireless Personal Area Networks (WPANs)

"Rail Safety Improvement Act of 2008"

Amendment X: Positive Train Control (PTC) System Physical Layer

of the United States Congress

NOTE—The editing instructions contained in this amendment define how to merge the material contained therein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strikethrough~~ (to remove old material) and underscore (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Deletions and insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make changes in figures or equations by removing the existing figure or equation and replacing it with a new one. Editing instructions, change markings, and this NOTE will not be carried over into future editions because the changes will be incorporated into the base standard.

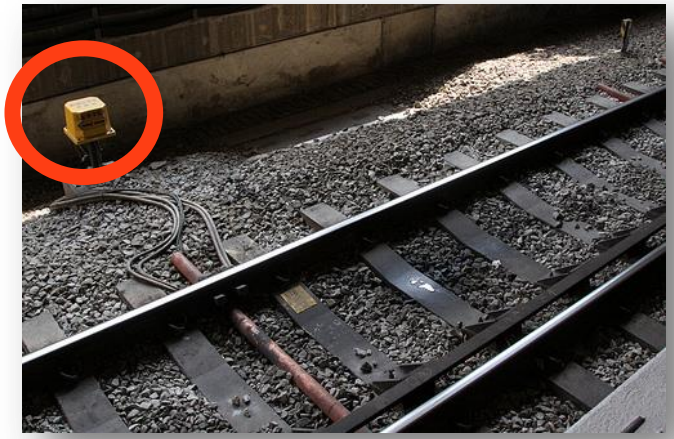
Dedicated Mobile Commu. for Rail

CTCS-4	➢ GSM-R
CTCS-3	➢ GSM-R & Balise and rail circuit
CTCS-2	➢ Balise & Rail circuit
CTCS-1	➢ Main locomotive signal & Safe operation monitoring and recording device
CTCS-0	➢ Universal cab signal & Operation monitoring and recording device

Dedicated Mobile Commu. for Rail

- ETCS1/ CTCS2 use Rail Track Circuit and Balise to transmit train control signals

Rail Track Circuit



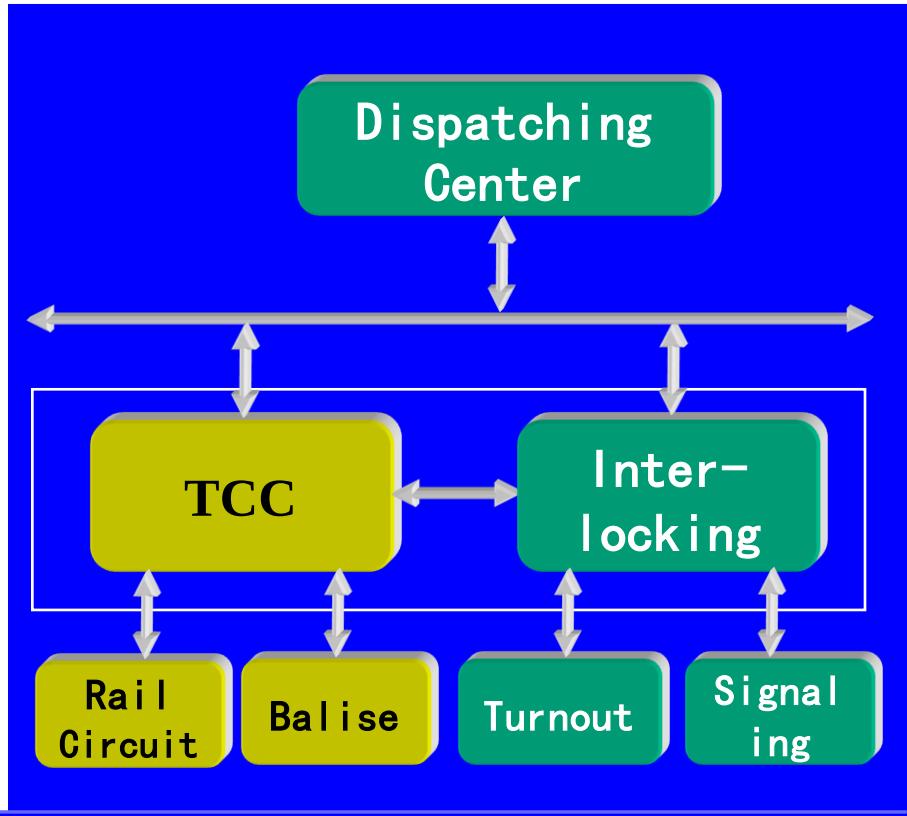
Balise

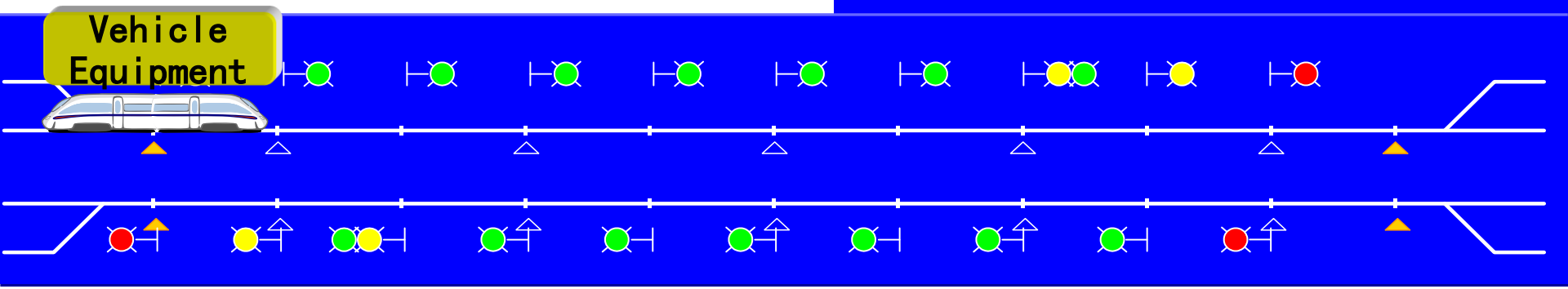


Dedicated Mobile Commu. for Rail

CTCS2 Level

Train Operation Control System

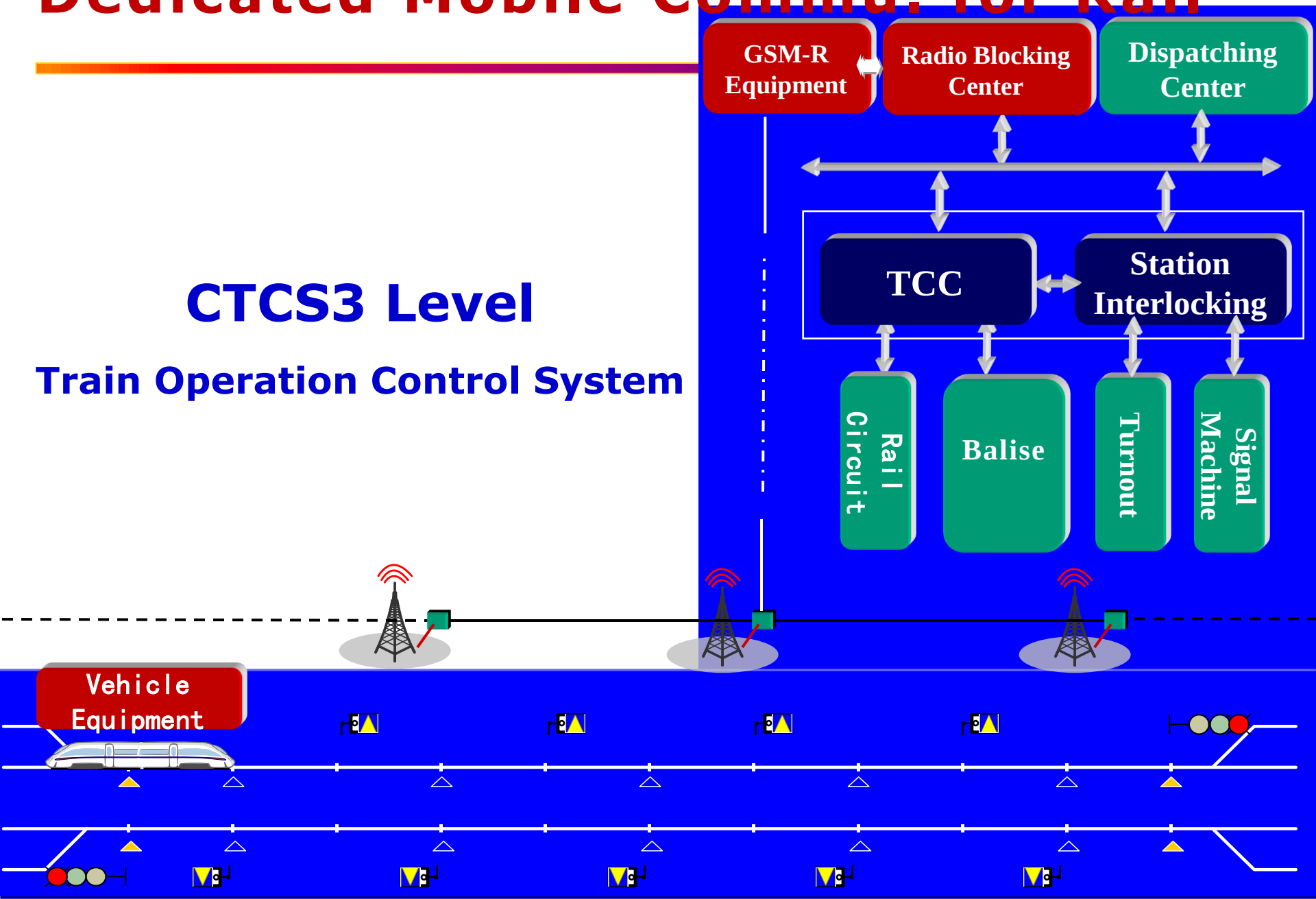




Dedicated Mobile Commu. for Rail

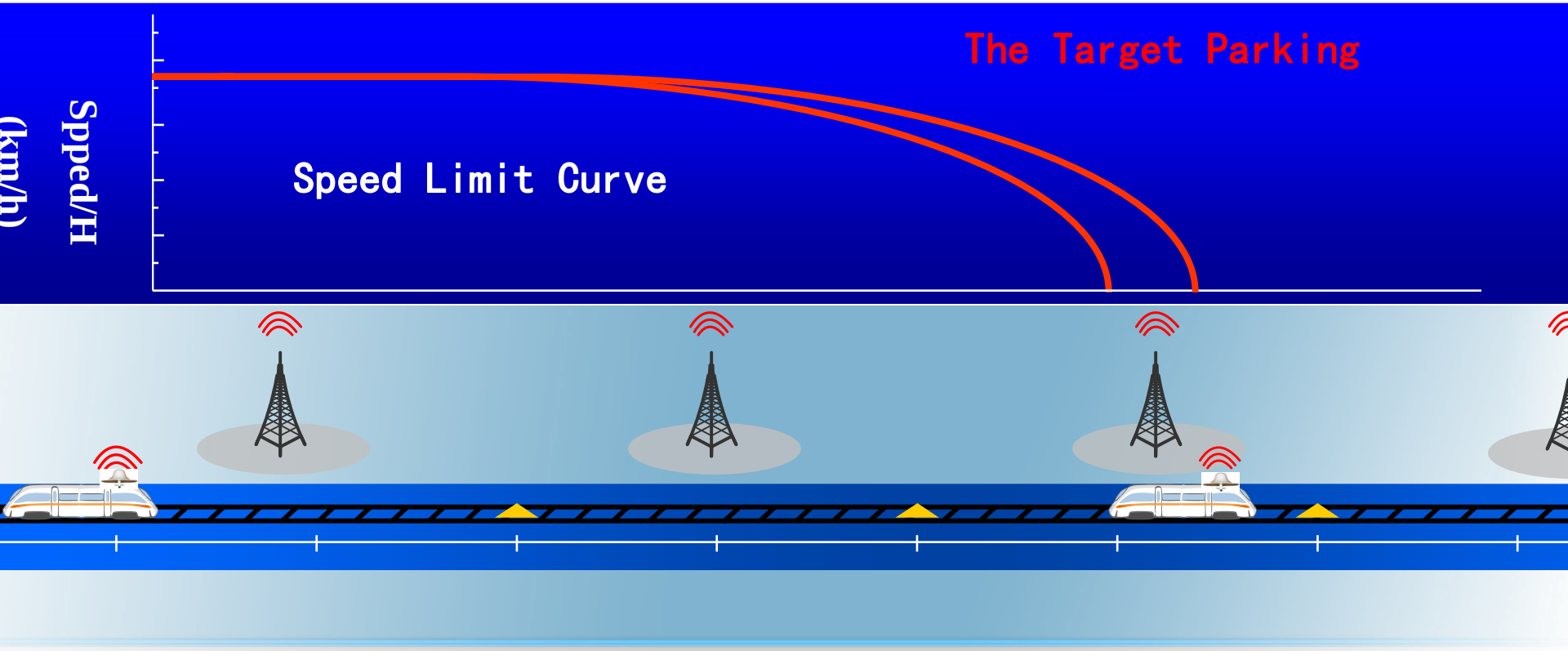
CTCS3 Level

Train Operation Control System



Dedicated Mobile Commu. for Rail

CTCS3 Tracking Operation Simulation



Dedicated Mobile Commu. for Rail

To provide reliable transmission of train control data to train control systems.

- **Special Scenarios**
- **High Moving Speeds**
- **High Quality of Service**
- **Various Interferences**

Bo Ai *et al*. Challenges towards Wireless Communications for High-Speed Railway. *IEEE Transaction on Intelligent Transportation System*, 2014.

Dedicated Mobile Commu. for Rail

Special Scenarios



Business indoor, Neighborhood indoor/outdoor, Home, Urban Vehicular, Urban Pedestrian outdoor, Rural outdoor, Terrestrial aeronautical, Fixed outdoor, Local high bit rate environments, Urban satellite, Rural satellite, Satellite fixed-mounted, Indoor satellite environments. No scenarios for HSR.



Defines a smaller set of radio propagation environments which adequately span the overall range of possible environments. No scenarios for HSR.



Scenario: 'LOS' and 'NLOS' for outdoor environments ; only 'OLOS' for indoor environments. No scenarios for HSR.



Defines four typical scenarios including in and around building, hot spot area, metropolitan and rural scenarios. The only one scenario appropriate for HSRs defined in WINNER project is WINNER D2 model (Rural moving network)

Dedicated Mobile Commu. for Rail

Special Scenarios









Dedicated Mobile Commu. for Rail

Special Scenarios









Dedicated Mobile Commu. for Rail



High speeds

Dedicated Mobile Commu. for Rail

120－140km/h：normal speed railway
140－160km/h：fast speed railway
160－200km/h：quasi high speed railway
200－400km/h：high speed railway
400km/h： higher speed railway
600 km/h: ultra high speed railway





Dedicated Mobile Commu. for Rail



High speeds

- Non-stationary characteristics
- Large Doppler frequency shift
- Frequent Handover
- Fast Switching of Different Scenarios
- Strict requirement of fast computing

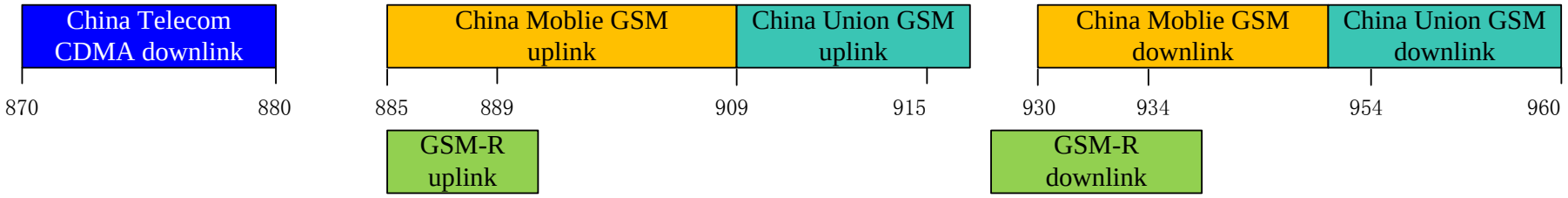
Dedicated Mobile Commu. for Rail



- QoS Indexes for Train Control
- Strict Requirement for Time Delay
- Higher Coverage Probability

QoS Items	Value
Connection Establishment Delay	<8.5s(95%), ≤100s(100%)
Connection Establishment Failed Possibility	<10^(-2)
Connection Failure Rate	≤10^(-2)
End-To-End Transmission Delay	≤0.5s(95%)
Transmission Interference Time	<0.8s(95%), <1s(99%)
Transmission Error-Free Time	>20s(95%), >7s(99%)
Network Registration Delay	≤35s(99%), ≤40s100%)

Dedicated Mobile Commu. for Rail



- Adjacent Channel Interference
- Severely Limited Frequency Resource
- Strong Electromagnetic Interference

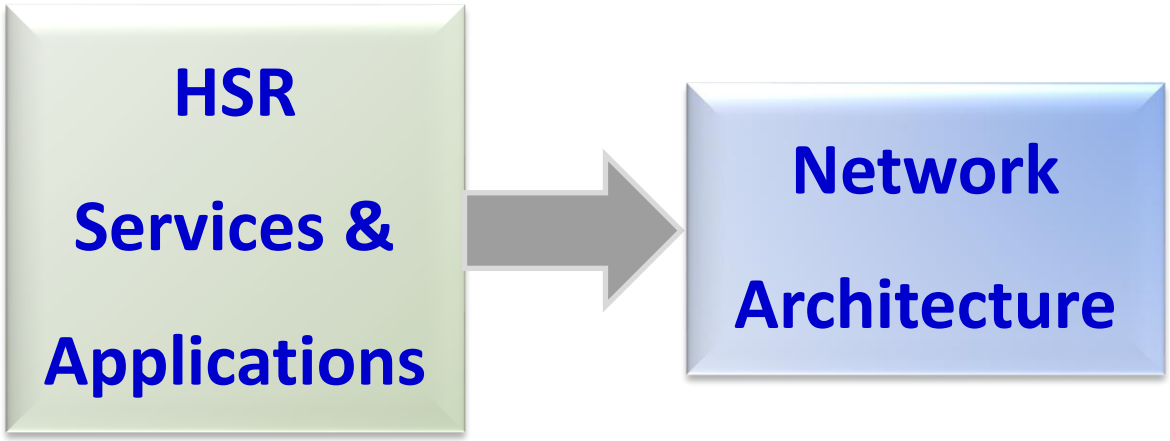




Outline

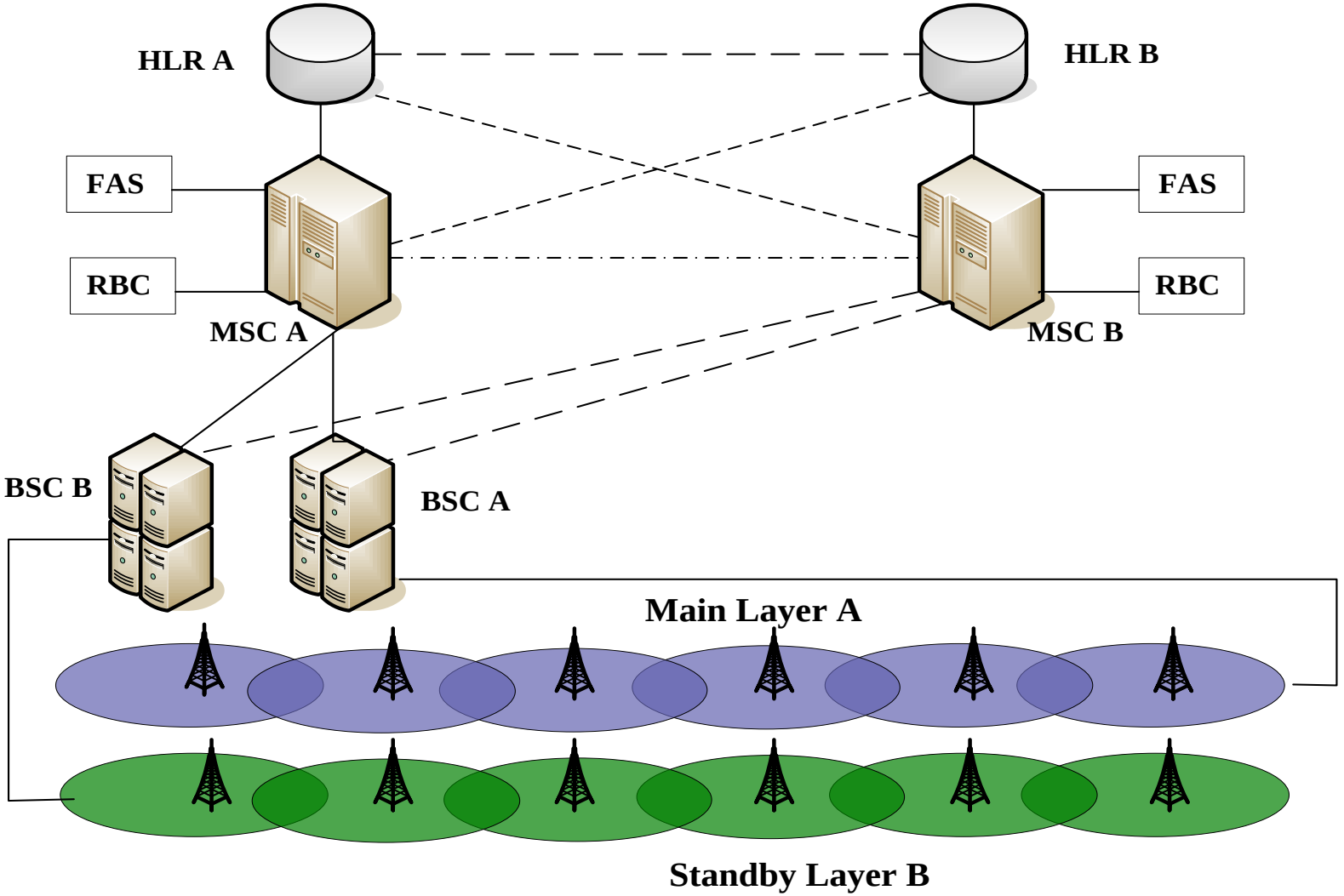
- Development of HSR in the World
- Dedicated Mobile Commu. for Rail
- **Hot Topics**

Hot Topics



- Big Data
- Services, traffic & user behavior model

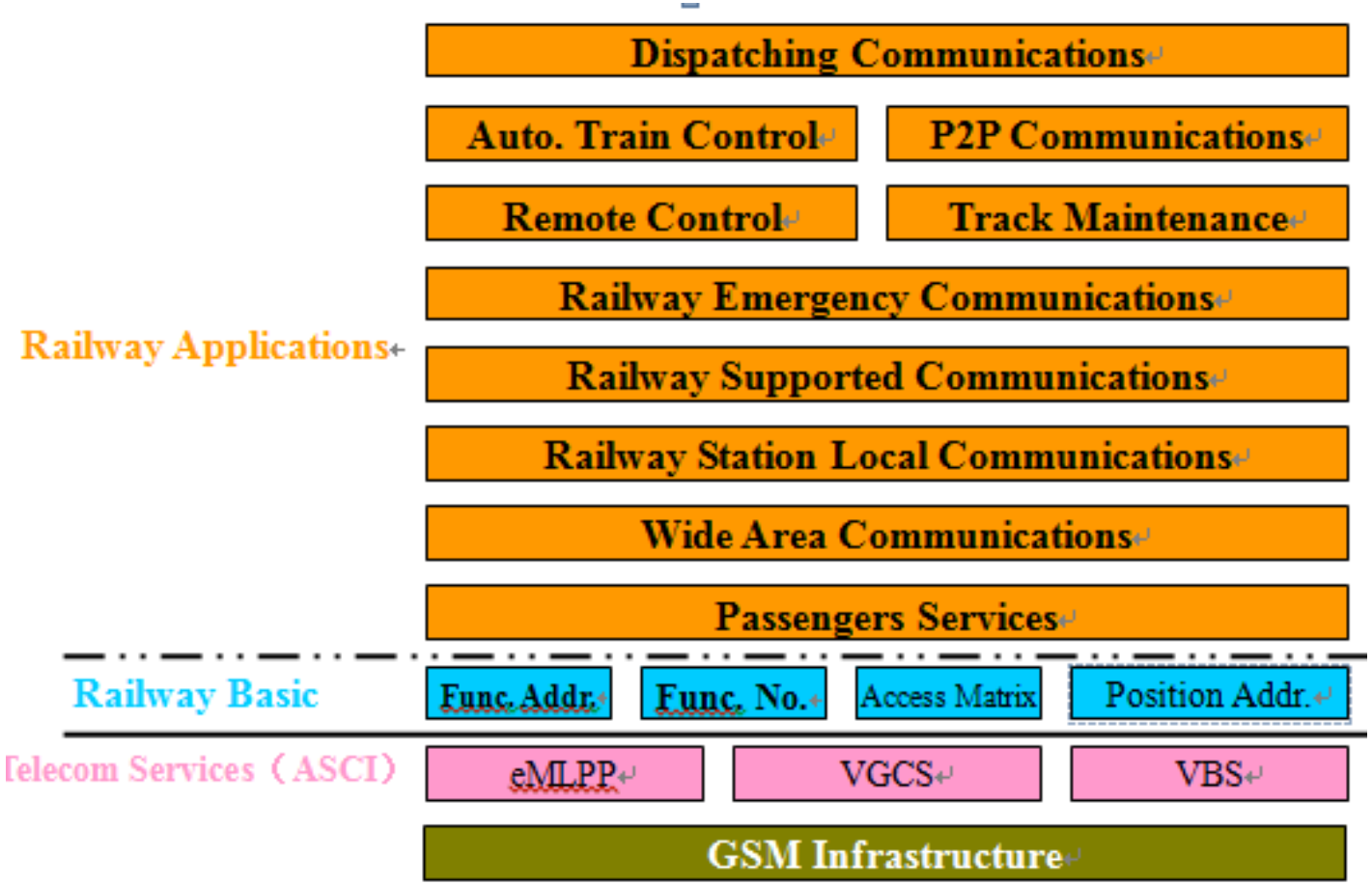
Network Architecture：GSM-R



GSM-R Network

Network Architecture：GSM-R

GSM-R Services = Voice Dispatching Services + Railway Basic Services＋Railway Applications



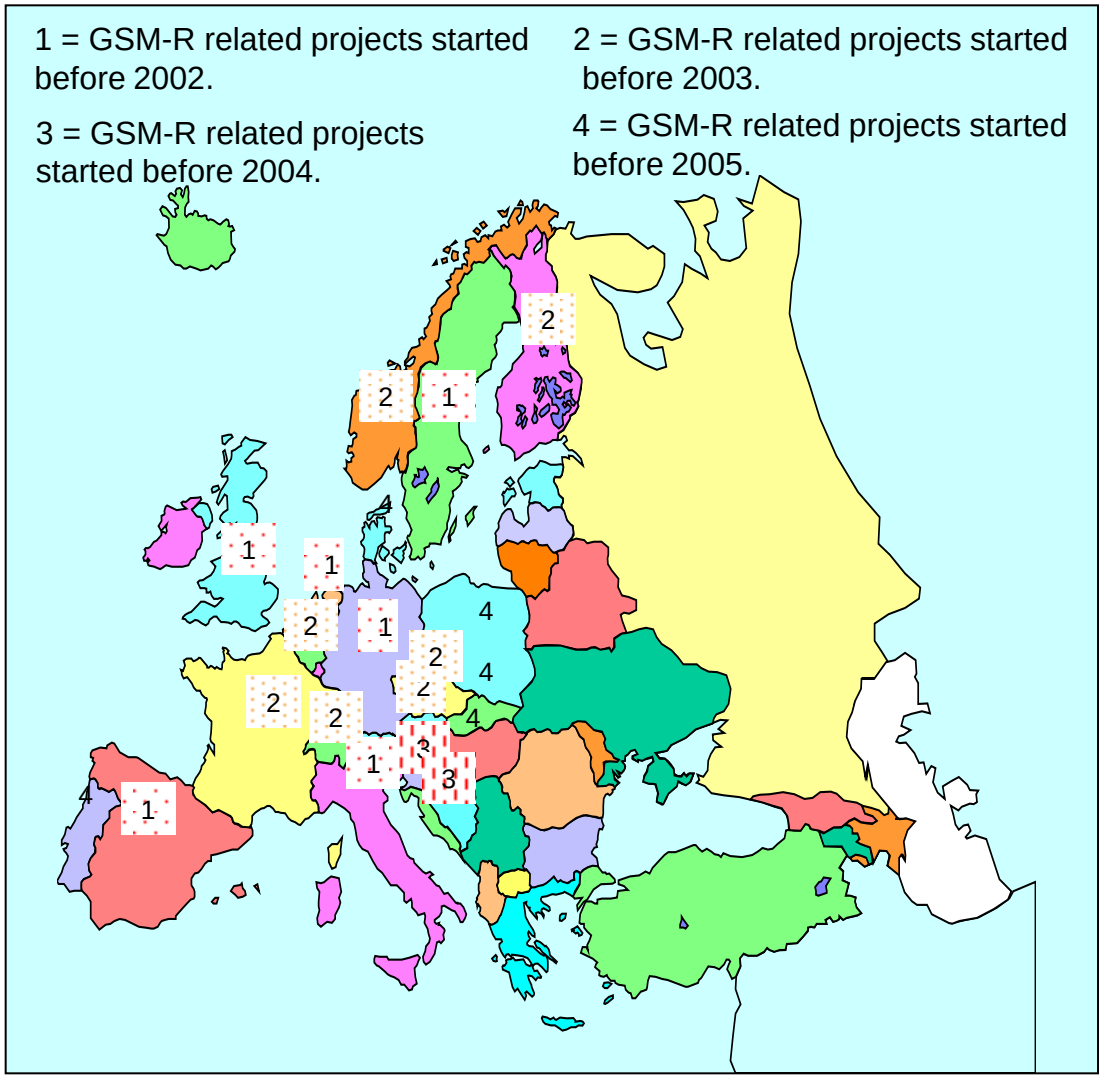
Business Hierarchy Diagram for GSM-R System

Network Architecture：GSM-R

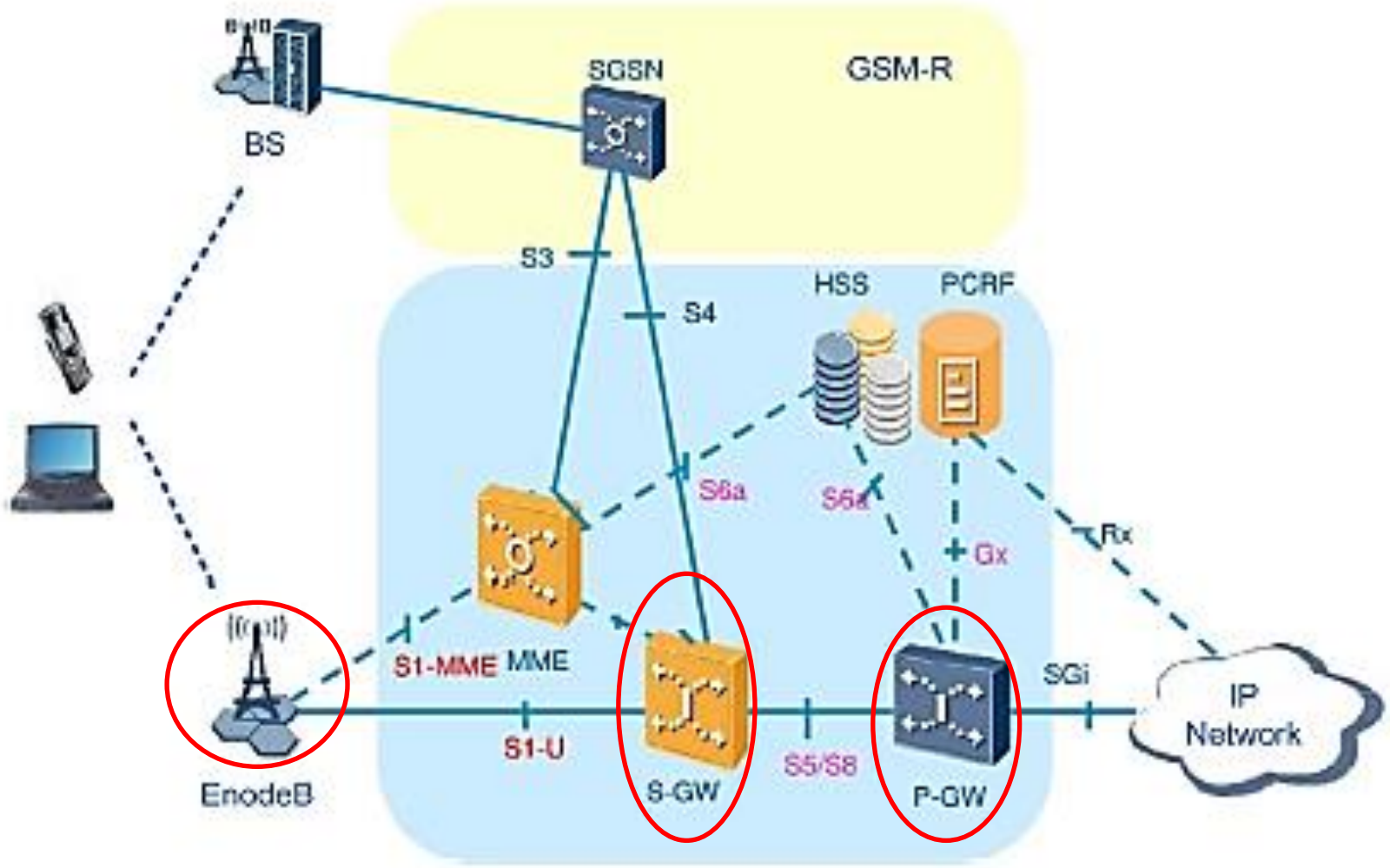
- 2 countries in 1999
- 7 countries in 2002
- 15 countries in 2005

  German 、 Sweden 、 Italy 、 Great British、Holland、Spain、Belgium、Fenland、France、Norway、Swiss、India、China…

- 34 countries in 2008
- 56 countries in 2012



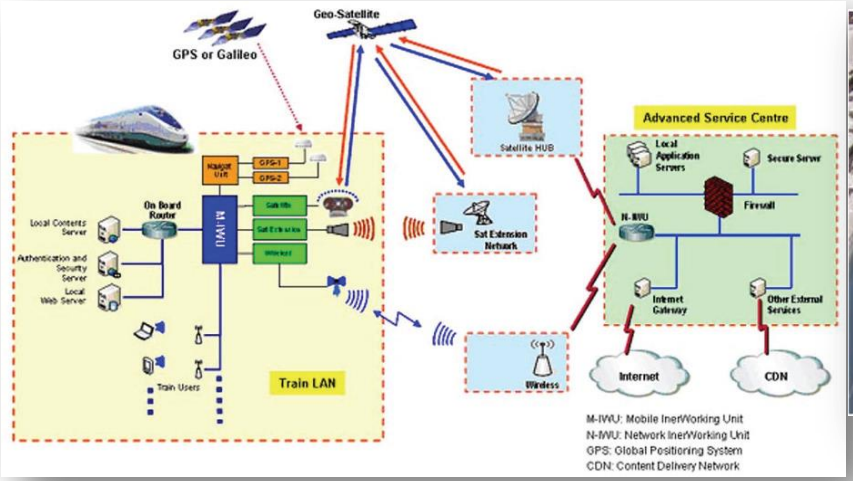
Network Architecture：LTE-R



LTE-R Network

Network Architecture：LTE-R

- Thalys HSR Communication System in France :
  Satellite Communication + WiMax
- Over 60,000 Passengers in Thalys share the broadband Wireless Internet Access Services at the speeds of 300km/h
- The evaluation of the Internet services in Thalys are good or very good.

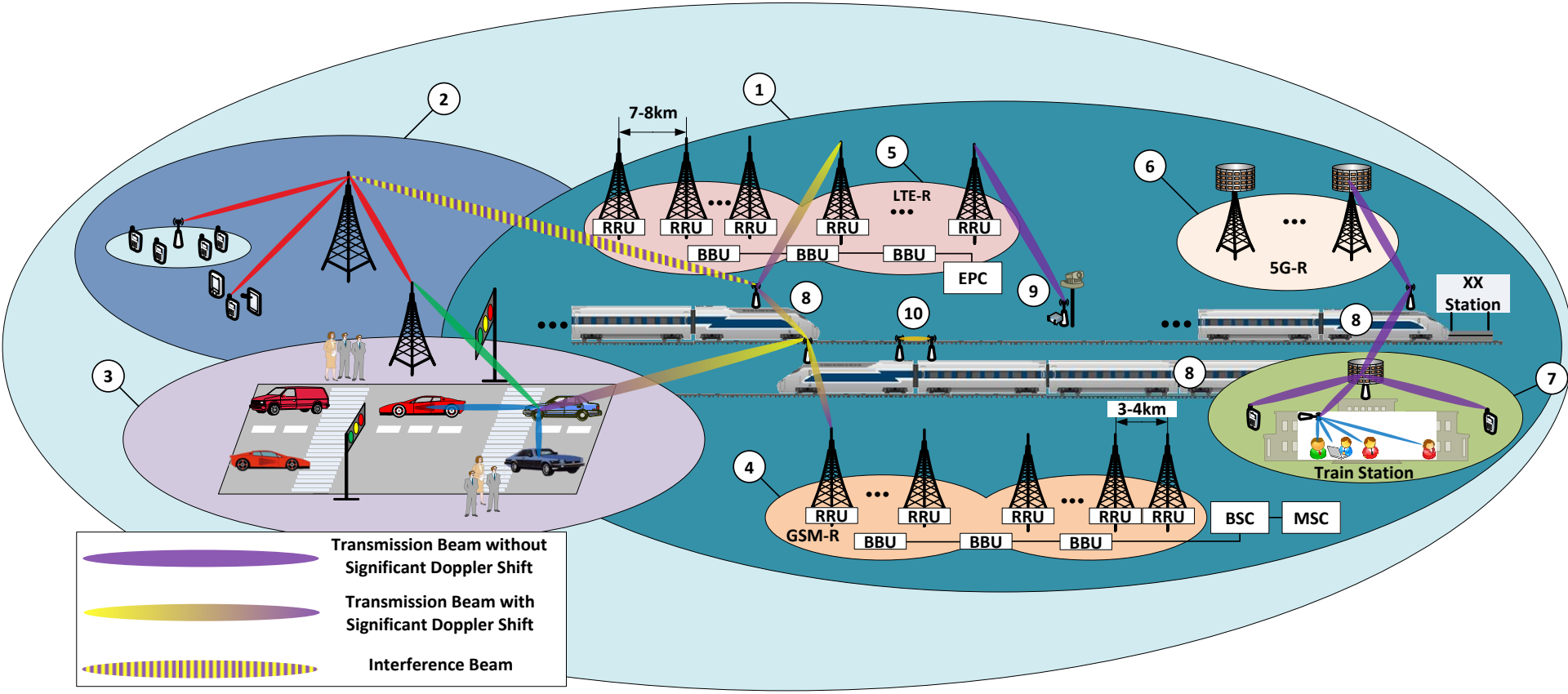






Thalys HSR Communication System

Network Architecture: 5G-R



Heterogeneous Network

Bo Ai *et al*. Future Railway Services Oriented Mobile Communications Network. *IEEE Communications Magazine*, 2015.

Network Architecture：5G-R





- Network Architecture & Management

- Research Innovation Technology Administration

Network Architecture: Dedicated SN



CYBER-PHYSICAL-SOCIAL SYSTEMS

Editor: **Liuqing Yang**, Colorado State University, liuqing.yang@ieee.org

Social Network Services for Rail Traffic Applications

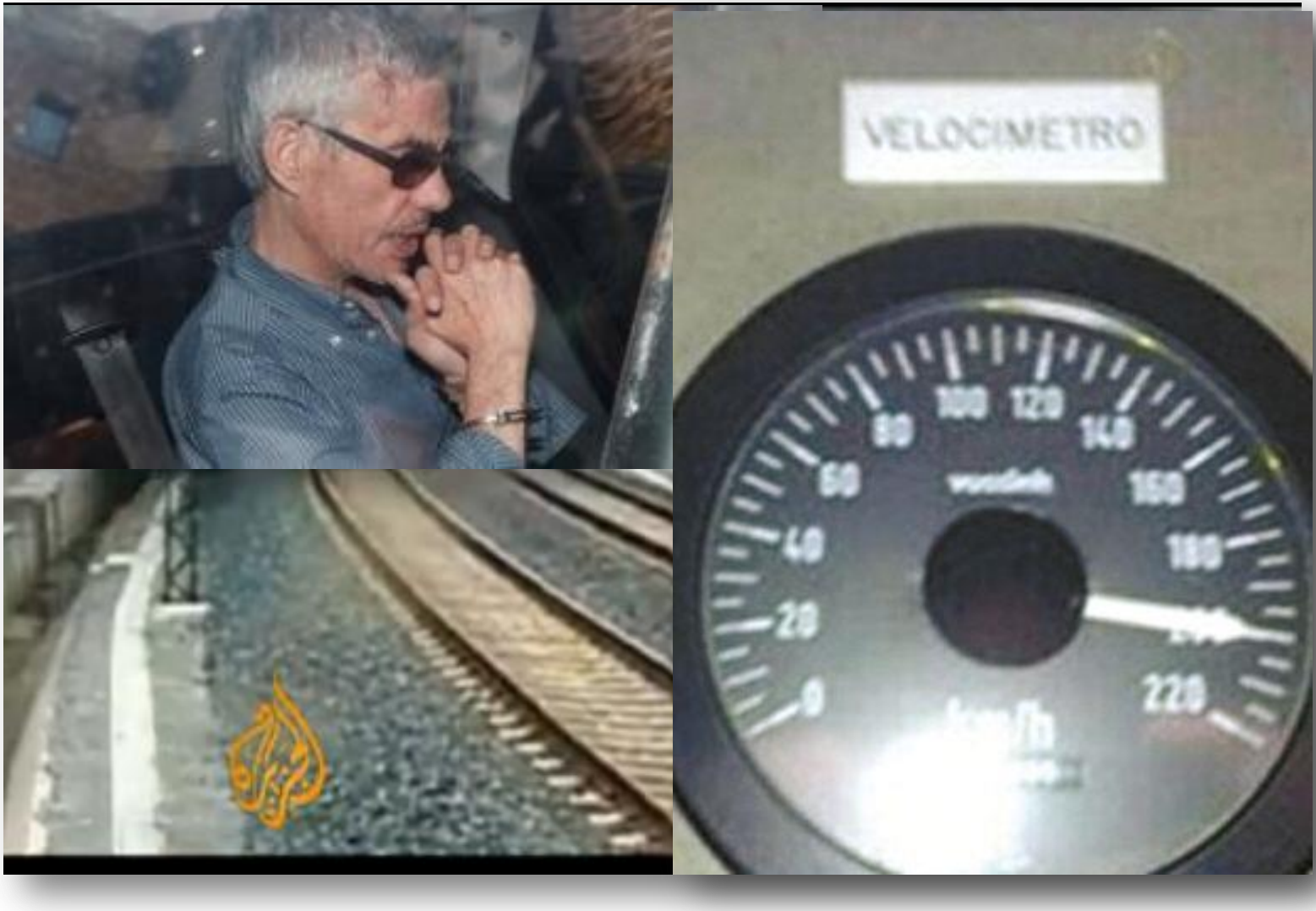
Bo Ai, *Beijing Jiaotong University*
Xiang Cheng, *Peking University*
Liuqing Yang, *Chinese Academy of Sciences*
Zhang-Dui Zhong and Jian-Wen Ding, *Beijing Jiaotong University*
Hua Song, *Engineering University of Armed Police Force, China*

The constructions of the high-speed railway, the subway, the intercity rail, and the rail intelligent transportation system (RITS) have been booming rapidly in recent years. The maximum train moving speed in the actual railway line has reached nearly 575 km/h, trialed by the French National Rail Corporation. The maximum moving speed in a test bed has reached 605 km/h, trialed by the China South Locomotive Group. As reported in other work,[1] the highest daily record for Beijing's urban rail transportation reached 5.71 million passenger trips in 2010.With the development of rail traffic transportation system, we need to address not only the operation reliability and safety, but also the elimination of the boredom and fatigue feelings for the passengers on long trips. People

So how do we fully exploit highly developed wireless communications, the Internet, and the positive role of people in the rail traffic transportation background? The current social network service (SNS) is a good choice, and the key issue is how to make good use of it. SNS can be regarded as a collection of social interactions constructed by relations among the group members.[7] It transfers Internet-based instant messaging, the contents of emergency broadcasting, real-time messages via email, microblogging, micro letters, flying letters, and blogs. Famous SNS tools include Facebook, Twitter, Windows Live Spaces, Foursquare, RSS, Flickr, YouTube, Digg, Mini-feed, Fexion, Video-Mail, Myspace, and so on. There are also professional social network sites for business people and scholars such as LinkedIn and Research-

Bo Ai *et al.*, "Social Network Services for Rail Traffic Applications," *IEEE Intelligent Systems*, vol. 20, no. 6, pp. 63-69, 2014.

Network Architecture: Dedicated SN



Network Architecture: Dedicated SN

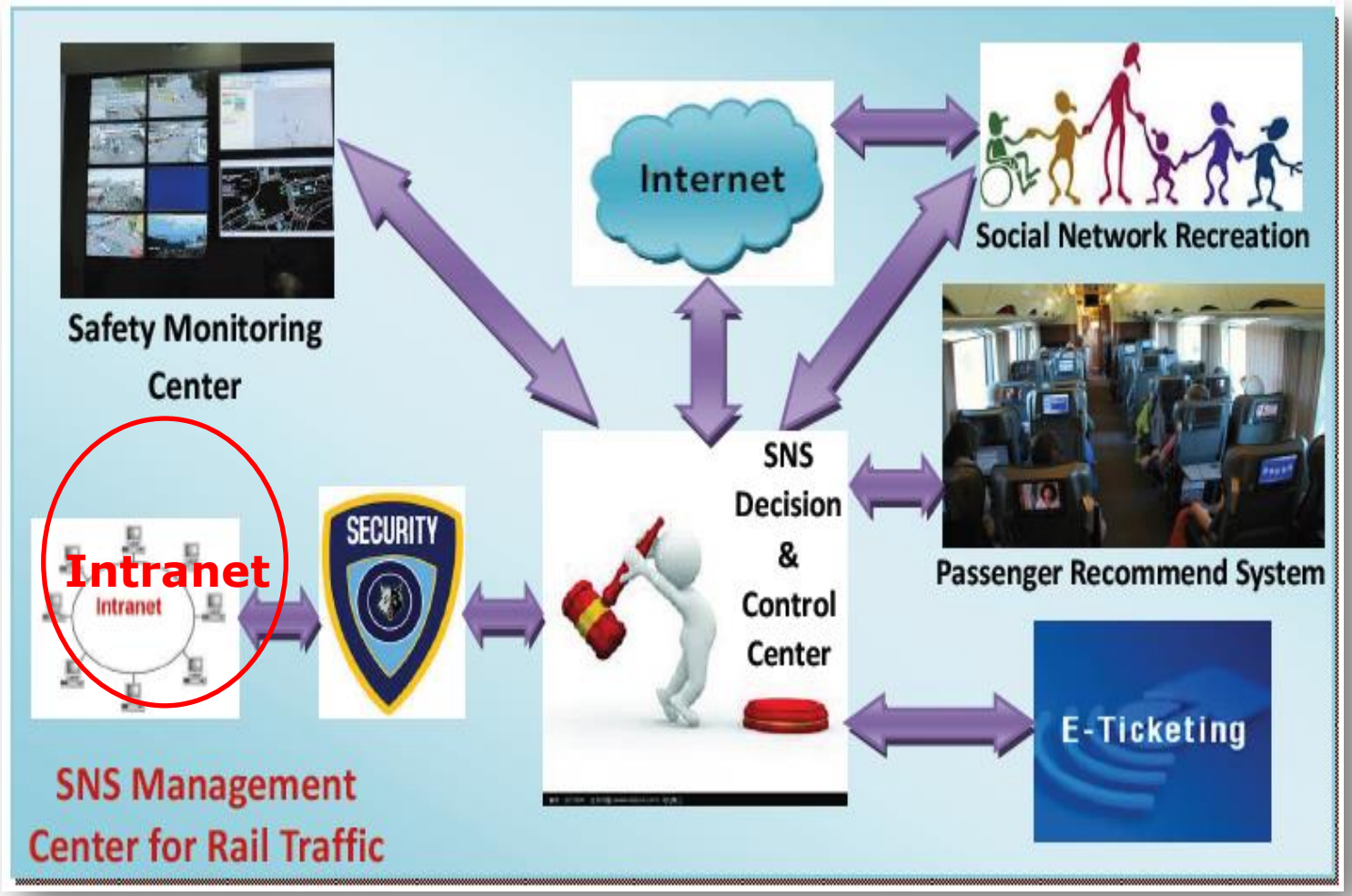
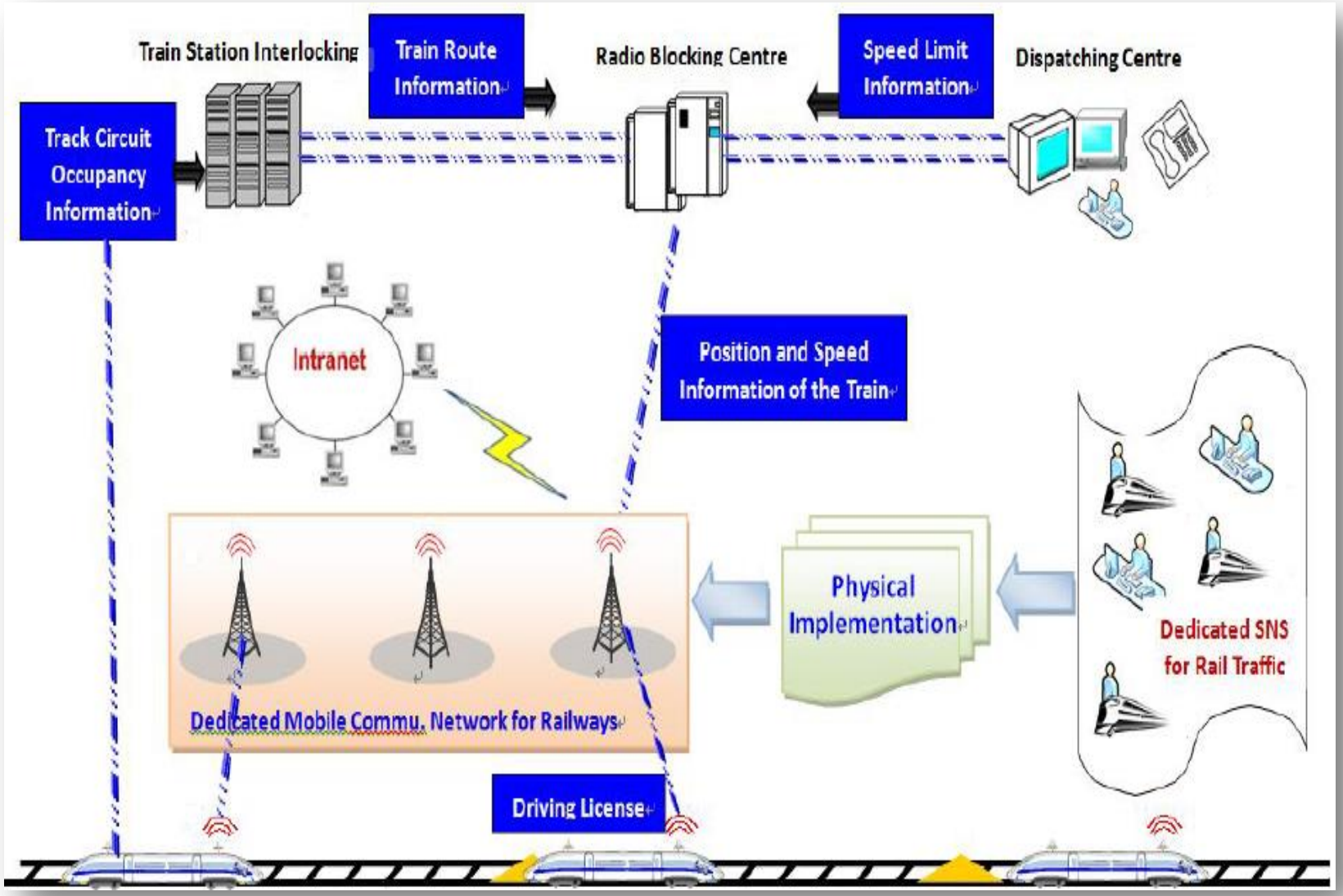


Diagram of SNS Management Center for Rail Traffic Transportation Systems

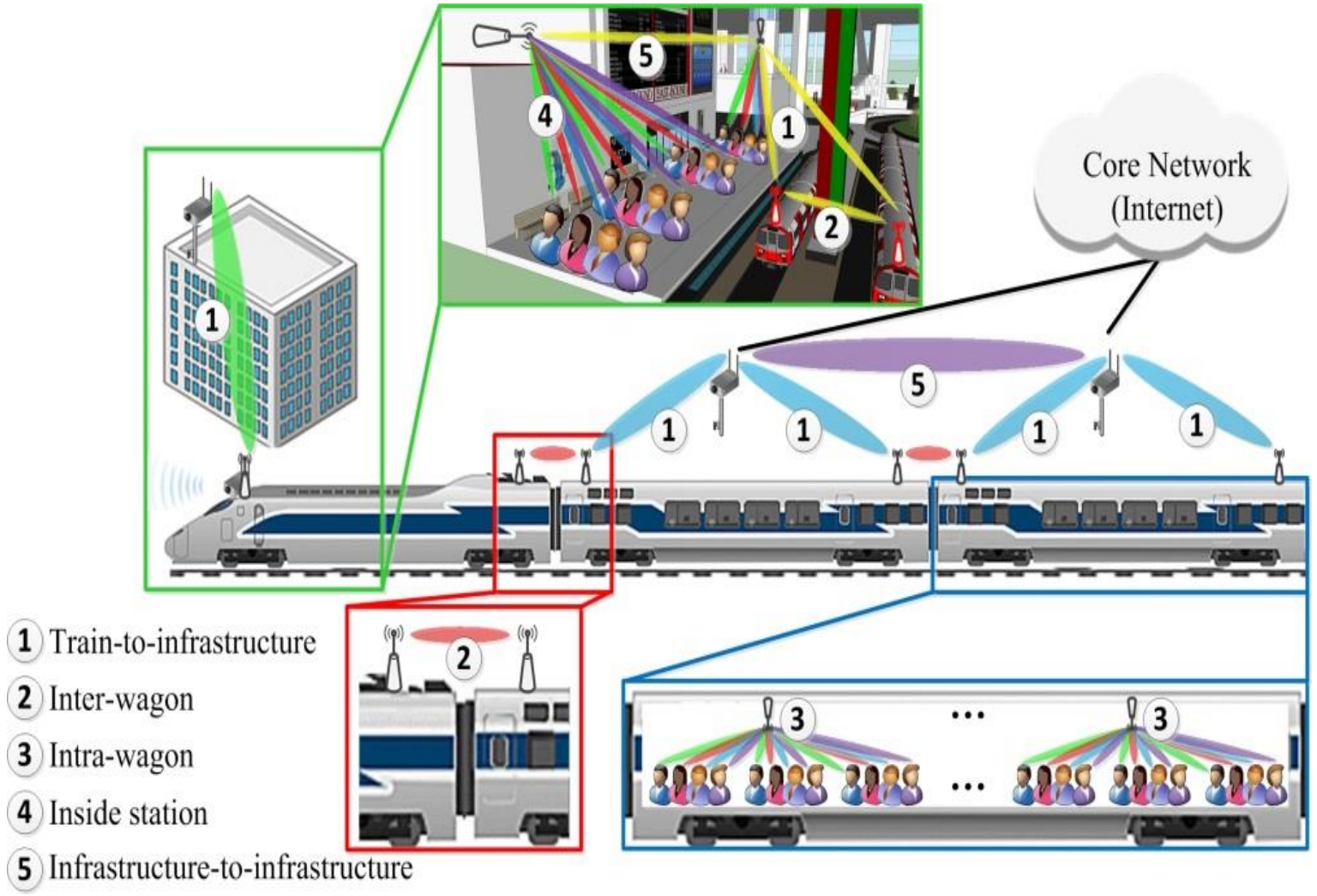
Network Architecture: Dedicated SN



SNS Diagram of Intranet for Internal Communications

Channel models

Railway Communication Scenarios



Channel models

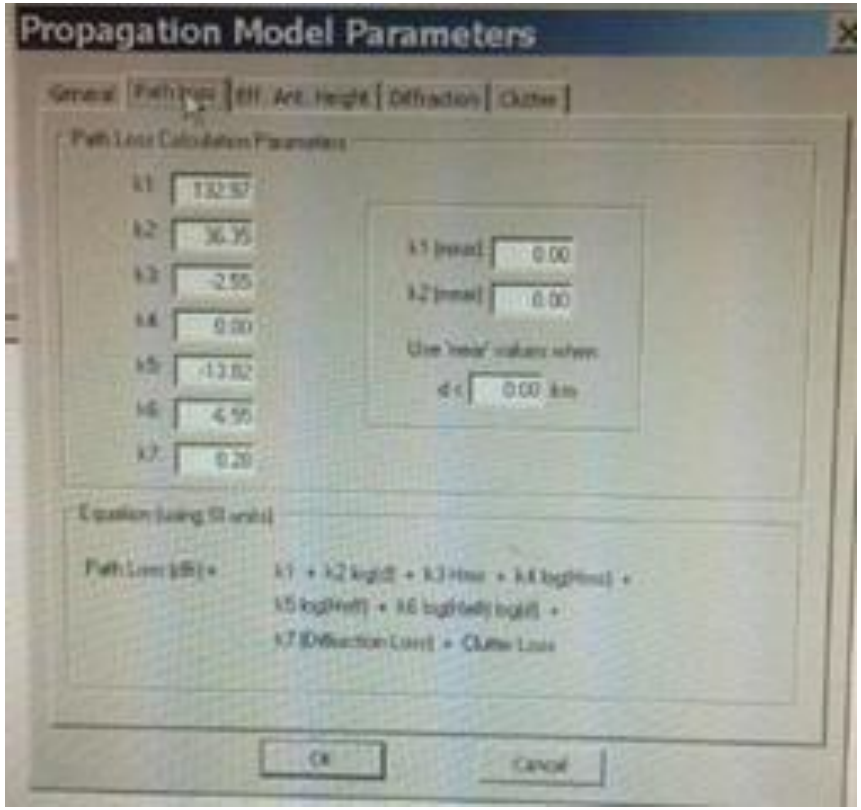
- GSM-R Channel Models
- LTE-R Channel Models
- 5G-R Channel Models

GSM-R Channel models

Hata Model

$$\mathrm{PL}_{\mathrm{Aircom}}(\mathrm{dB}) = K_1 + K_2 \log_{10}(d) + K_3 h_m + K_4 \log_{10}(h_m) + K_5 \log_{10}(h_b) + K_6 \log_{10}(h_b)\log_{10}(d) + K_7 + C_{\mathrm{Loss}}$$

Aircom Company



GSM-R Channel models

Test Parameters				Values			
Test Line				Zheng-Xi			
Scene	Cell number	Scene	Cell number	Scene	Cell number	Scene	Cell number
Urban	33	Rural	415	Cutting	730	Mountain	276
Suburban	1253	Viaduct	1254	Station	461	River	172
Sampling Interval				10cm			
Statistical Interval				40λ			
Test Samples				23 million samples			

GSM-R Channel models

Scenario	Definition	LOS/NLOS	Speed(Km/h)	Frequency (MHz)	Special Propagation Mechanism	Notes
1	Viaduct a	LOS	0-350	930		
2	Viaduct b	LOS	0-350	930		
3	Cutting a	LOS	0-350	930		
4	Cutting b	LOS	0-350	930		
5	Urban	LOS	0-350	930		
6	Suburban	LOS	0-350	930		
7	Countryside	LOS	0-350	930		
8	Tunnel	LOS	0-200	930	Waveguide Effect	
9	Railway Station	LOS/NLOS	0-80	930		
10	Marshaling Station	LOS	0-80	930		
11	Rivers	LOS	0-350	930	Mirror Reflection	
12	Relay	LOS/NLOS	0-10	930		
13	Bad Scenario a	NLOS	0-350	930	Diffraction	Deep Fading
14	Bad Scenario b	LOS/NLOS	0-350	930	Far-end Reflection	Time Delay
15	Mountains	LOS/NLOS	0-100	930	Mountain Reflection	
16	Sands	LOS	0-350	930	Scattering	

GSM-R Channel models

Basic Formula	$\begin{aligned}\mathrm{PL(dB)} &= A + B\log_{10}(d) \\ &= \Delta_1 + 74.52 + 26.16\log_{10}(f = 930) \\ &\quad - 13.82\log_{10}(h_b) - 3.2\log_{10}(11.75h_m)^2 \\ &\quad + [44.9 - 6.55\log_{10}(h_b) + \Delta_2]\log_{10}(d)\end{aligned}$
Urban	$\Delta_1 = -20.47$ $\Delta_2 = -1.82$
Suburban	$\Delta_1 = 5.74\log_{10}(h_b) - 30.42$ $\Delta_2 = -6.72$
Rural	$\Delta_1 = 6.43\log_{10}(h_b) - 30.44$ $\Delta_2 = -6.71$
Viaduct	$\Delta_1 = -21.42$ $\Delta_2 = -9.62$
Cutting	$\Delta_1 = -18.78$ $\Delta_2 = 51.34\log_{10}(h_b) - 78.99$
Station	$\Delta_1 = 34.29\log_{10}(h_b) - 70.75$ $\Delta_2 = -8.86$
River	$\Delta_1 = 8.79\log_{10}(h_b) - 33.99$ $\Delta_2 = -2.93$

Channel models

- GSM-R Channel Models
- **LTE-R Channel Models**
- 5G-R Channel Models

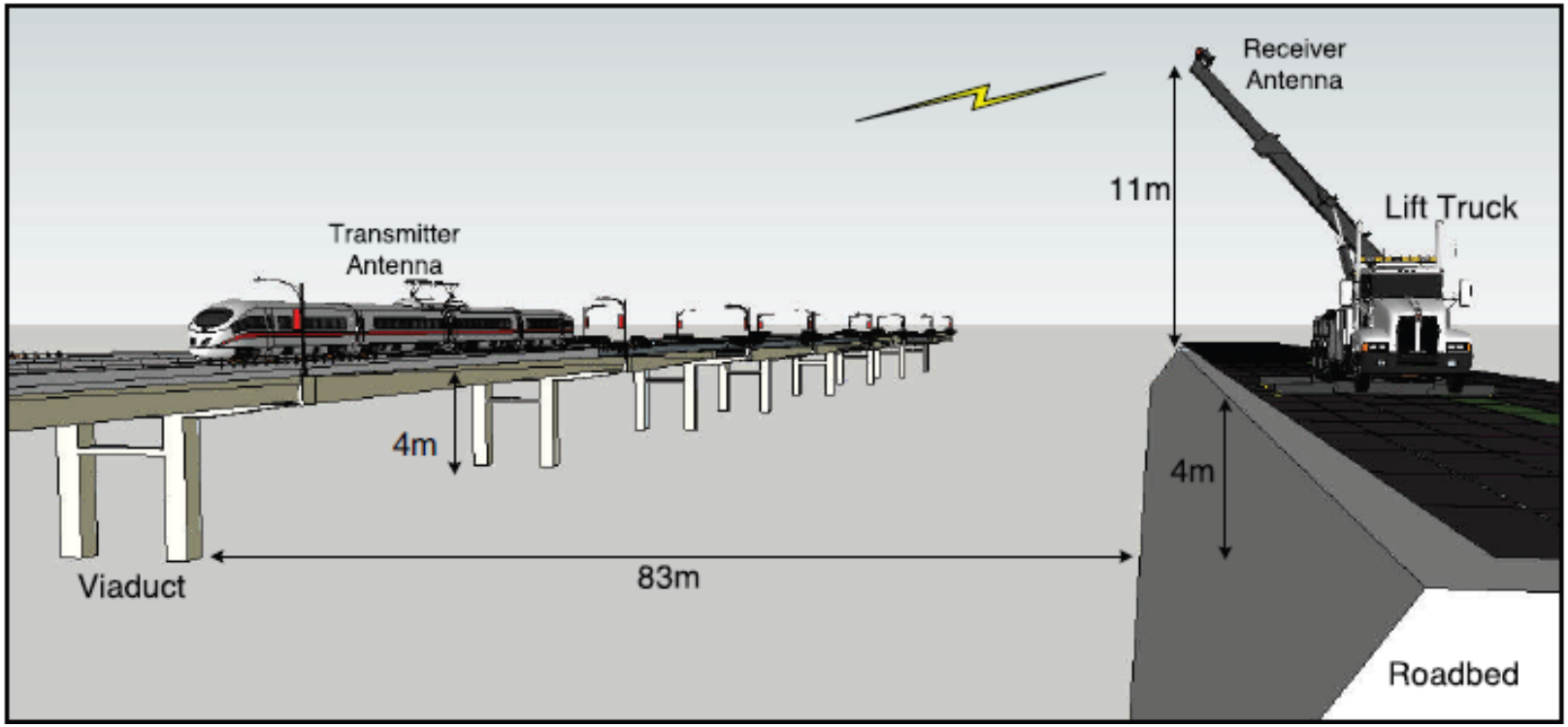
LTE-R Channel models

- 3G —— Spatial Channel Model (SCM)
- 3.9G —— SCM Extension (SCME)
- 4G —— WINNER Phase I Model (WIM1)
- 4G —— WINNER Phase II Model (WIM2)

3GPP、COST 、IEEE——No Standard Channel Models for HSR

WINNER D2 model (Rural moving network)

LTE-R Channel models

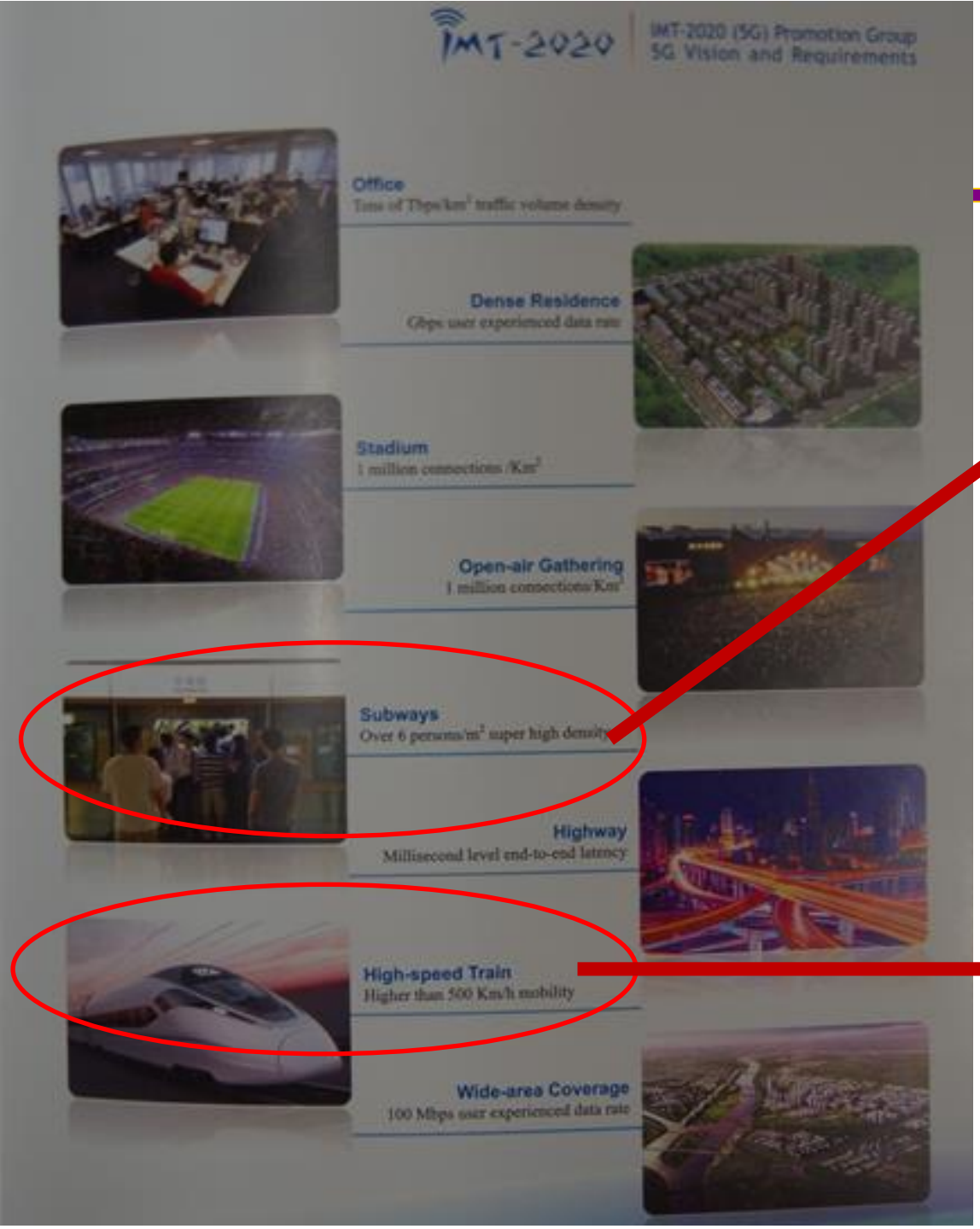






Channel models

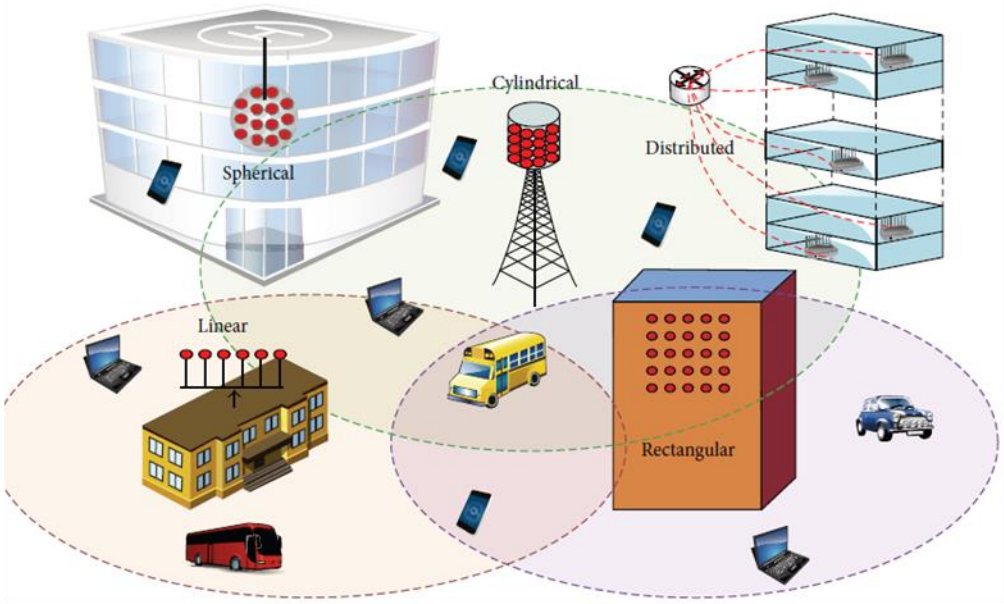
- GSM-R Channel Models
- LTE-R Channel Models
- **5G-R Channel Models**



Subways: Over 6 person/m² super high density

High-speed Train: Higher than 500 km/h mobility

5G-R Channel models



E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, "Massive MIMO for next generation wireless systems," *IEEE Communications Magazine*, vol. 52, no. 2, pp. 186–195, 2013.

Massive MIMO



Dense urban



Metro station



Train station



Carriage

5G-R Channel models

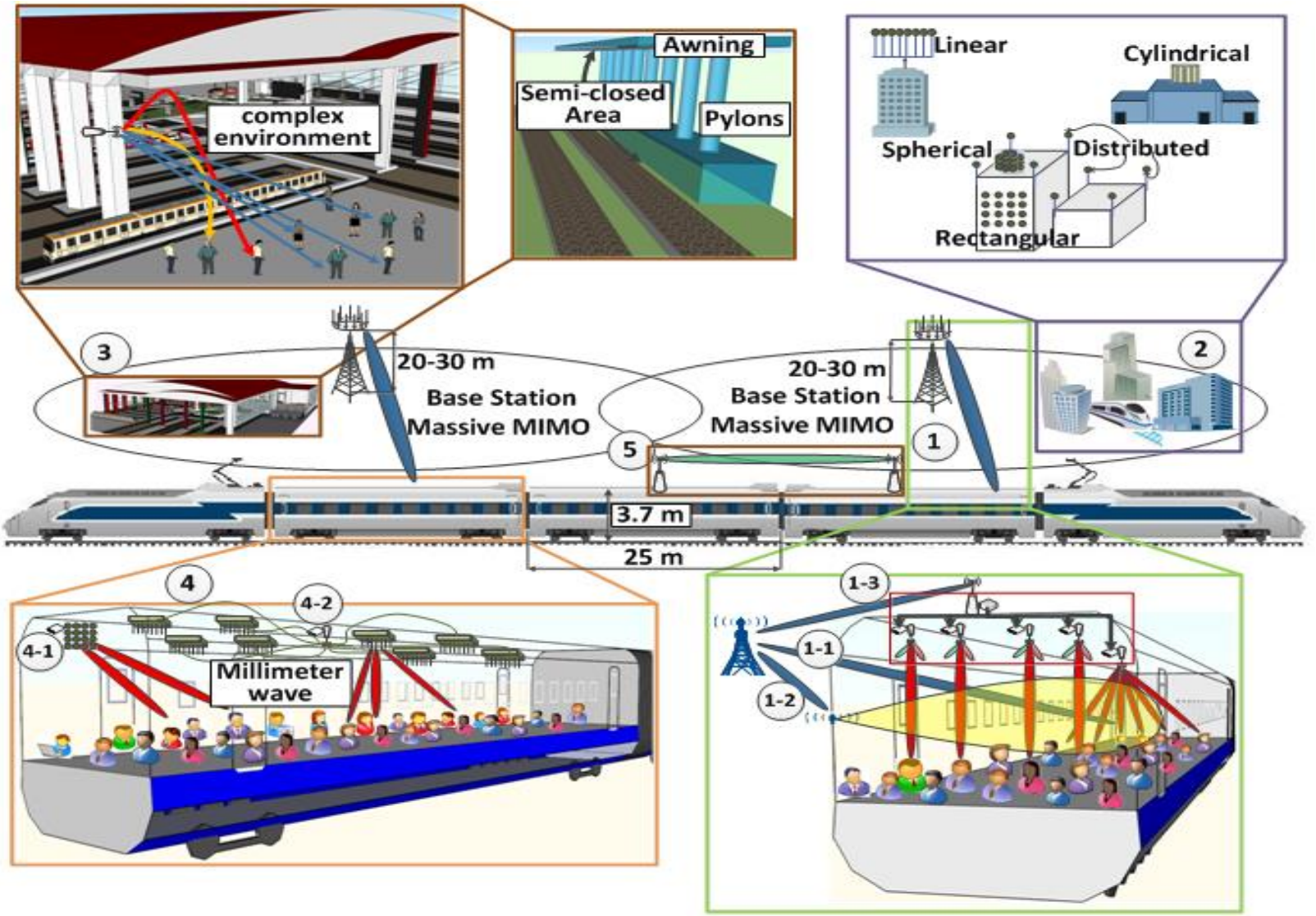


Fig. Massive MIMO Based Wireless Coverage for Railway Systems

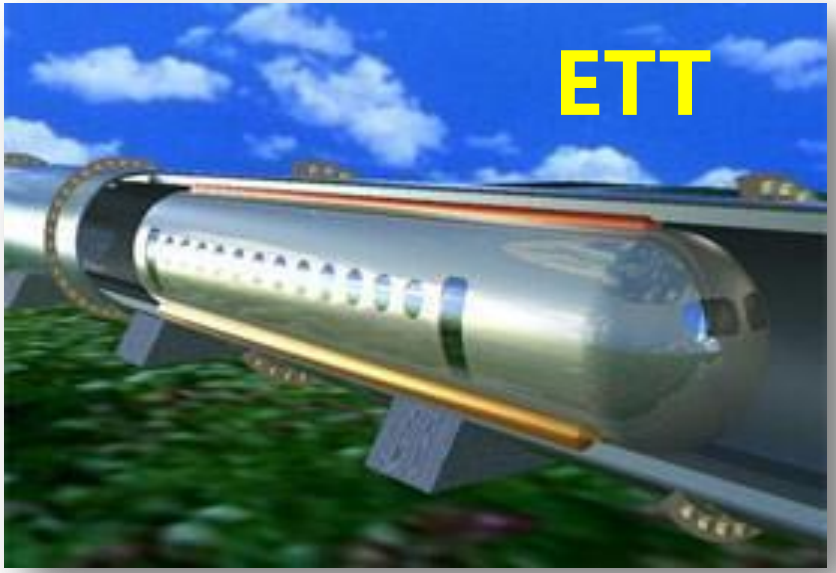
5G-R Channel models

Metrics

Frequency bands	Application scenarios	Antenna numbers	Antenna arrays
• Below 6GHz, • 11GHz,15GHz, 22GHz,28GHz, 38GHz,60GHz	• Outdoor：LOS+NLOS • Indoor：LOS+NLOS • Subway: LOS+NLOS • Inside rail wagons	• 64×1 • 64×64 • 128×1 • 128×128 • 256×256	• Linear • Rectangular • Cylindrical

- **Methodology and results of measuring massive MIMO channel from 6 GHz to 60 GHz, with 500 MHz bandwidth;**
- **Spherical or cylindrical wave based high resolution parameter extraction method;**
- **Cluster-of-scatterer (CoS)-based channel modeling method;**
- **Ray-tracing tools for massive MIMO channels;**
- **Massive MIMO channel models.**

Channel models



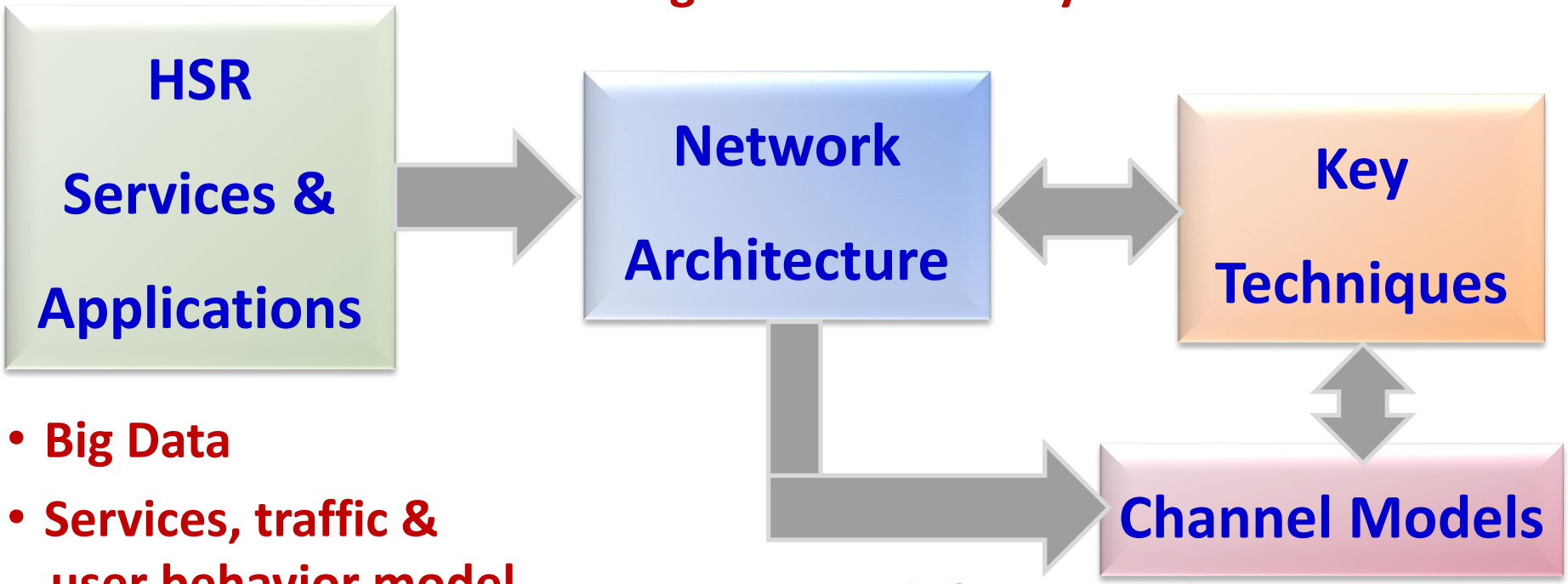






Hot Topics

- Heterogeneous network architecture
- Network interference management
- Network performance evaluation
- Seamless switching with low latency



- Big Data
- Services, traffic & user behavior model

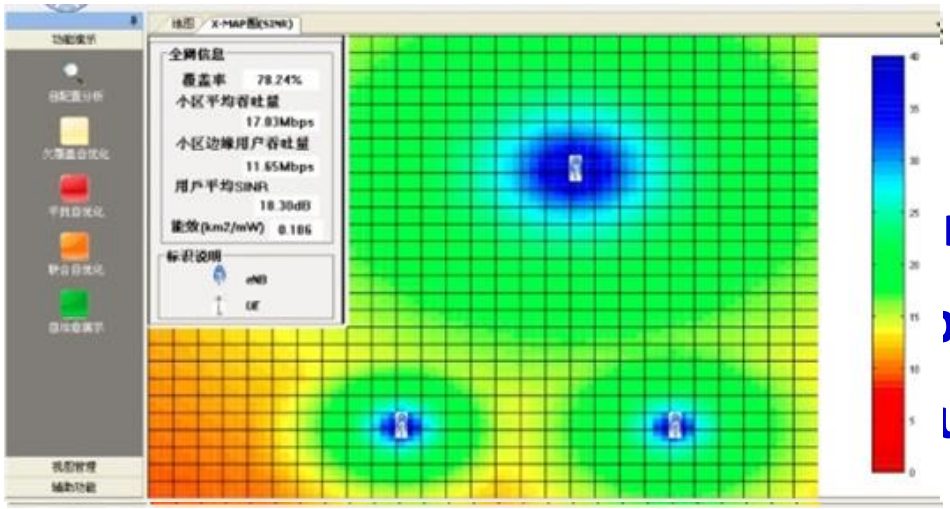
- High frequency bands, mm wave
- Different scenarios and app.
- Dynamic massive MIMO

Key Tech.: SON for Rail

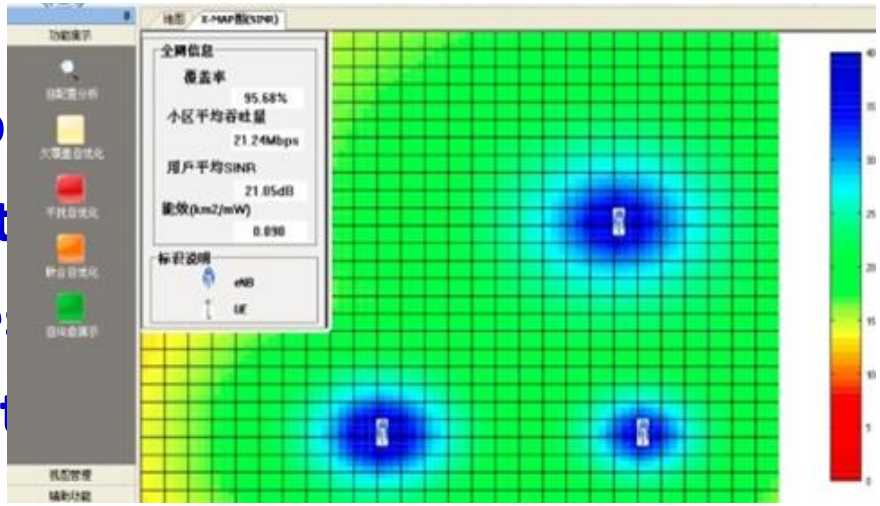




Sparse Passenger Flow

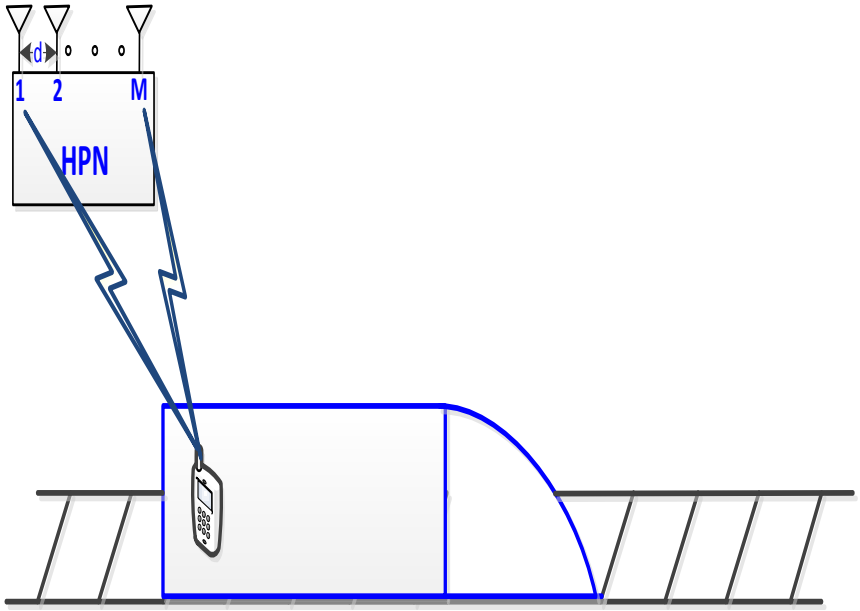


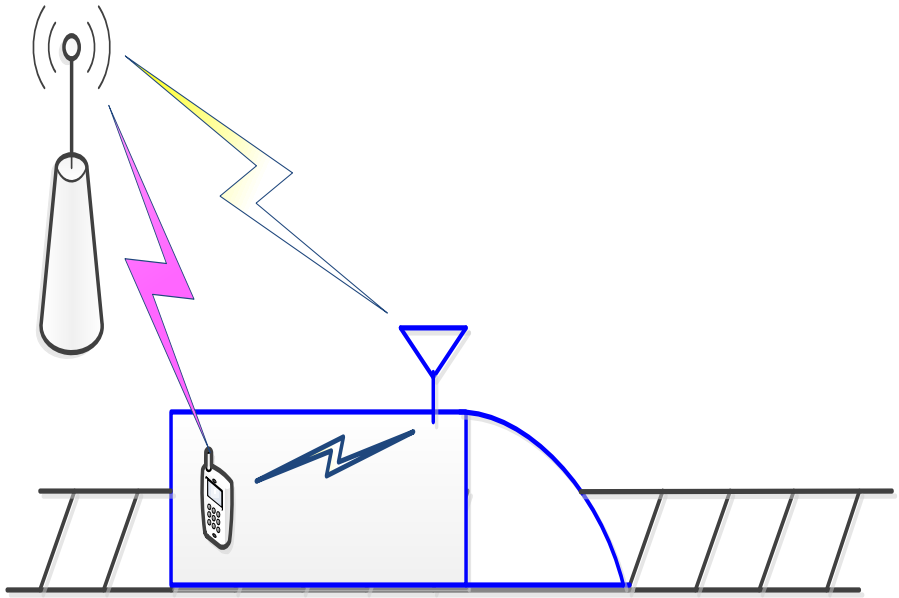
Dense Passenger Flow



Key Tech.

- Handover
- Channel Estimation
- Doppler Estimation





Speed: over300 km/h

Key Tech.: IoT for Rail

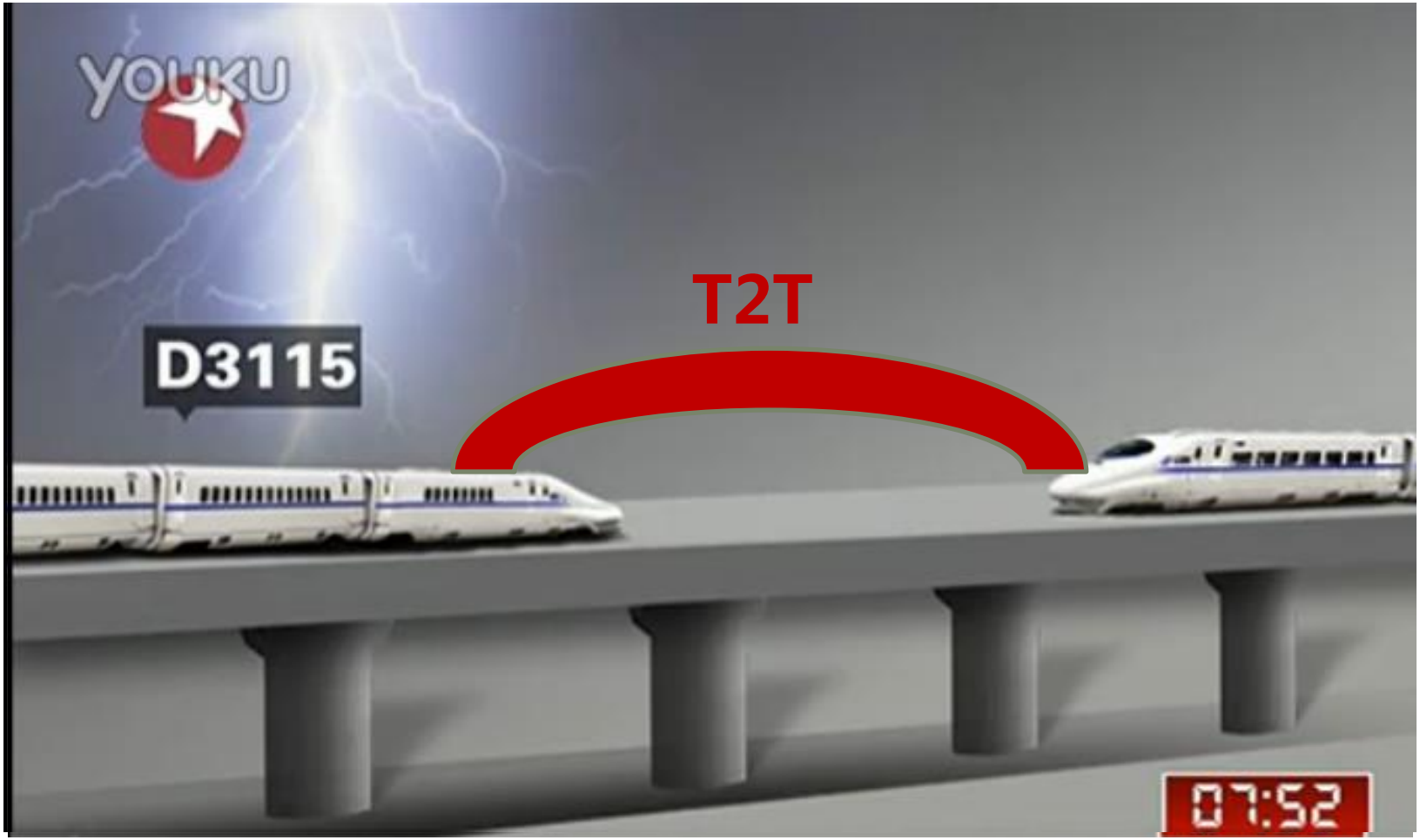






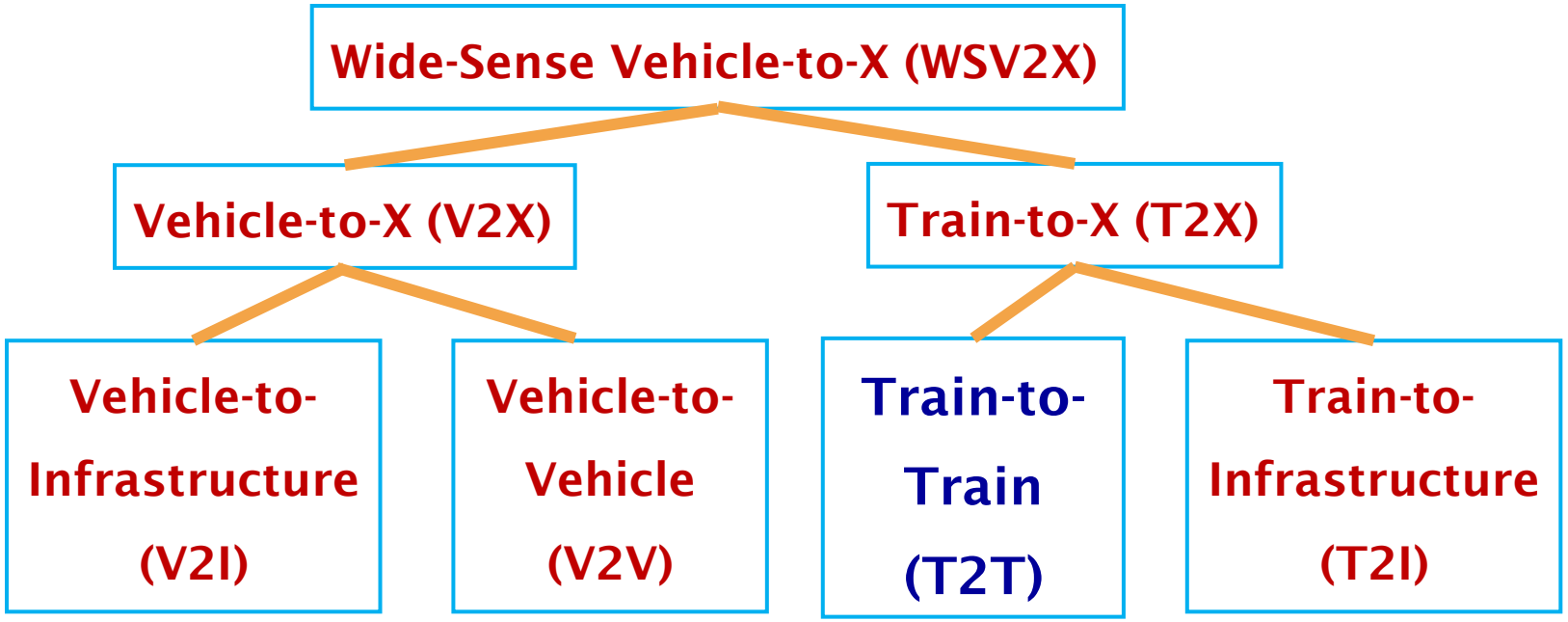
- Debris flow
- Broken bridges
- Subsidence
- Serious weather conditions
- …

Key Tech.: T2T



Key Tech.: T2T

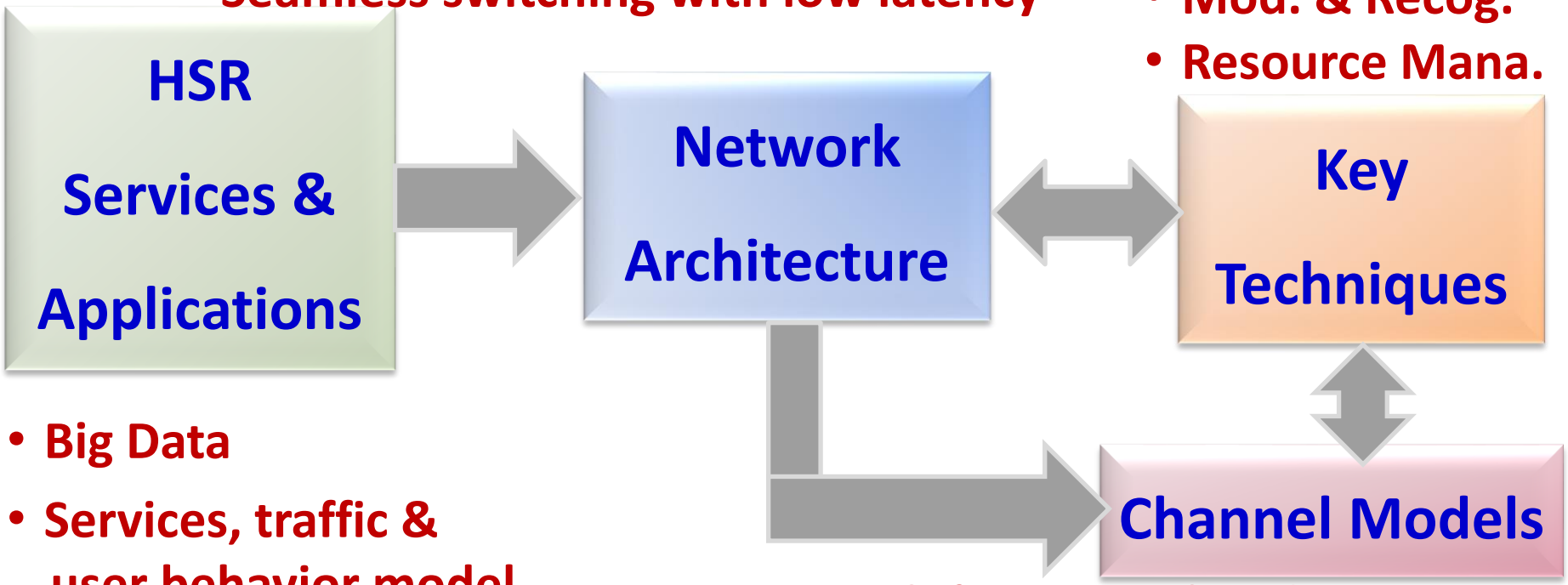
Other Auxiliary Safety Guaranteed Measures?



Hot Topics

- Heterogeneous network architecture
- Network interference management
- Network performance evaluation
- Seamless switching with low latency

- CoMP & Spectr. sensing
- Relay Commu.
- Mod. & Recog.
- Resource Mana.



- Big Data
- Services, traffic & user behavior model

- High frequency bands, mm wave
- Different scenarios and app.
- Dynamic massive MIMO


Thank you!