Future Cellular Networks for a Society in Motion
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A look into our future

• Mark Twain: Prediction is difficult – especially for the future

• The UN expects that by 2050 about 86% of the world's population lives in cities. Thus number of cities and city sizes will grow

• This new life-style will also have a deep impact on wireless communications!
A look into our future

• In 2050 we will have only two different scenarios for wireless cellular systems:

• 1) Nomadic (quasi-static) use for people in or around buildings. Buildings provide wireless infrastructure just as they do today for water and energy. Small picocells possibly by light ensure high data rates and low latencies.
Are We All Becoming Mobile, App-Armed Superheroes?
2) People and Devices are on the move
A look into our future

• 2) People and Devices are on the move:
  – Public transportation
    • such as Trains, Busses, Subways, Trams, Airplanes
  – Individual Traffic
    • Cars2go, rental cars, delivery services,
    • governmental services such as police, fire trucks, emergency vehicles

• The choice of transportation means is less and less defined by transportation time and more and more defined by internet access!
A look into our future

• What data traffic is generated in 2050?

• People will serve the internet for
  – Relaxation (music, videos, gaming)
  – Information (news, time tables, etc.)
  – Preparation (before and after work)

• Machines will serve the internet for
  – Traffic control, safety, traffic logistics
A look into our future

• A Society in Motion thus requires a Dependable Internet Service (DIS)
  – Various data traffic requires different rates and latency constraints to function properly

• The challenge is to offer such DIS
  – Everywhere
  – Cost efficiently
  – Reliably
Outline

• Motivation (is already over...)

• High Velocity Challenges
• evolved Multimedia Broadcast Multicast System
• Distributed Antennas
• Heterogeneous Networks

• Conclusions
High Velocity Challenges

- SIR \propto \left( \frac{\Delta f}{f_c \cdot v} \right)^2

\Delta f = 15\,\text{kHz},\ f_c = 2.5\,\text{GHz}

- Signal to Interference Ratio (dB)
- Velocity (km/h)

- Measured
- Uniform

- \Delta f \ldots \text{subcarrier spacing}
- f_c \ldots \text{carrier frequency}
- v \ldots \text{velocity}
High Velocity Challenges

• Single Pilot Pattern
• One for DL
• One for UL

• Independent of
  – RMS delay spread
  – **RMS Doppler spread**
High Velocity Challenges

- Optimal pilot pattern and power allocation
High Velocity Challenges

• Iterative receiver approach
High Velocity Challenges

• Iterative receiver approach

![Graph showing Bit Error Ratio vs. estimated Signal-to-Noise Ratio](image-url)
High Velocity Challenges

• OFDM can be improved considerably by
  – Optimal pilot pattern
  – Optimal power allocation
  – Iterative receiver approaches

• 5G proposes Filter Bank Multi Carrier (FBMC)
  – Higher spectral efficiency without CP
  – Can directly match user velocity constraints
  – Can address users with different velocities

• Differential Modulation still not advancing
eMBMS
• evolved Multimedia Broadcast Multicast System
• Along motorways
eMBMS

• Along train tracks
Experiment

CAM: Cooperative Awareness Messages

• 7 cars per cell, 3 cells
• Every car sends message to every other
• 3 background users to obtain remaining resources

• What is better?
• Unicast or Multicast?
Latency

8 x lower delay
Throughput
of background users

Significant throughput increase

Empirical Cumulative Probability

User Throughput [Mbit/s]

Multicast Transmission
Unicast Transmission
Distributed Antennas
Future Deployment
Compare centralized vs distributed antenna system
8x4 Antennas, 8 Users, 1 stream (ZF)

60km/h at 2GHz
~1969, Bell Labs
Richard Frenkiel & Philip Porter
Paradigm Change: ~2010

- HetNets: macrocells, microcells, picocells, femtocells...
- CoMP
- Separate uplink/downlink routes
- Direct D2D
Urban Environment

is not a flat plane

... but is rather characterized by building blockage ...

or so called indoor coverage ratio
Urban Environment

• We call this a 2-tier network
• HetNet= Heterogenous Network

... with outdoor macro BSs and indoor small cells

or so called small cell occupation
HetNets in Urban Environments

- Mayor influential factors are
  - Small cell occupation probability $\eta$
  - Wall penetration loss $L_w$
  - Indoor coverage ratio

(a) University of Texas at Austin
(b) Downtown Vienna
Univ.-Prof.Dr.-Ing. Markus Rupp
HetNets in Urban Environments

• Precise prediction by modelling:
HetNets

• But not only static buildings can host their own small cells
• All traffic vehicles can do that
  – Trains, trams, cars, ...
• They do not only need to provide traffic to their inside passengers but can work as moving small cell!
Conclusions

• Let us take a view on some 5G concepts:
  • **mmWaves** work for short distances only
    – Fantastic for indoor coverage
    – No use in high mobile scenarios
  • **Massive MIMO** requires static channel scenarios taking advantage of channel reciprocity
    – No use in high mobile scenarios
Massive Antenna Arrays
Massive Antenna Arrays

• Future cities will look like this?
Massive Antenna Arrays

- Alcatel Lucent (2013) 128 elements
- Bell Labs 1999 circular
Conclusions

• But modern concepts such as
  • FBMC for high velocities
  • Network densification by HetNets
  • Distributed Antennas
  • Broadcasting (eMBMS)

• Can really help and will be the future technology
Thank you for your interest!

• More details in
  – Markus Rupp and Stefan Schwarz

• Or simply under: mrupp@nt.tuwien.ac.at


[61] ——, “MIMO transmission over high delay spread channels with reduced cyclic prefix length,” in Proc. of Workshop on Smart Antennas (WSA ’15), Ilmenau, Feb. 2015.


[58] ETSI TS 102 637-2 V1.2.1, “Intelligent transport systems (ITS); vehicular communications; basic set of applications; part 2: specification of cooperative awareness basic service,” March 2011.


Backup
Some results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2.14 GHz</td>
</tr>
<tr>
<td>LTE bandwidth</td>
<td>$B = 5$ MHz</td>
</tr>
<tr>
<td>Shadow fading</td>
<td>fixed</td>
</tr>
<tr>
<td>Channel model</td>
<td>none</td>
</tr>
<tr>
<td>Receiver type</td>
<td>ITU-R Vehicular-A, block fading</td>
</tr>
<tr>
<td>Average noise power</td>
<td>zero forcing</td>
</tr>
<tr>
<td>Transmission rate</td>
<td>$-13$ dB</td>
</tr>
<tr>
<td>Scheduler</td>
<td>fixed, 1.2 bit per channel use (CQI 6)</td>
</tr>
<tr>
<td>Cyclic prefix</td>
<td>round robin multicast group scheduler</td>
</tr>
<tr>
<td>Simulation length in TTI</td>
<td>$N_{TTI} = 10,000$</td>
</tr>
</tbody>
</table>

(a) Signal to interference ratio 10 dB.

(b) Signal to interference ratio 20 dB.
Throughput [Mbit/s] vs SNR [dB] for different speeds:

- **Link level simulation**
- **System level simulation**

- 95% confidence interval

For speeds:
- 50km/h
- 300km/h
- 500km/h