The challenge of next decade mobile network and potential solutions

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Corporate Research
Content

• Mobile network traffic forecast
• Challenge
• Potential Solution
Beyond Voice: Changing Communications

Peer to Peer

2000
~ 0.7 Billion users
126 Billion minutes

2010
~ 5.4 Billion users
1620 Billion minutes
~ 5 Billion connections

One to Group

2020
~ 7.5 Billion users
3000 Billion minutes
~ 60 Billion connections

One to All, All to All
Traffic forecast on device

**Eyes**

- Limit to native resolution
  - 1080P @ 550DPI phone
  - 4K @ 550DPI tablet

- Display Power becomes content dependent

- Video complexity increase from 720P H.264 to 4K H.265

![Graph showing traffic forecast on device](image-url)
Beyond Phone: Changing Behaviors

Personal

Expanded

Infinite

2000
0.02x traffic
语音+SMS

2010
1x traffic
Internet

2020
~ 500-1000x traffic

容量=小区数*RF带宽*频谱效率

业务容量的根本问题在于频谱资源受限

容量=小区数*RF带宽*频谱效率
网络体验感官化，要求网络响应时间无限逼近人的反应时间

Response time = sensing + transmission + Processing + Muscle Movement

VS

Network:
Signal capturing + accessing + Computing + Rendering

挑战：

Human ≈ Netwrok
Content

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Network traffic Challenge: 1000X


If indoor traffic occupies 70%, outdoor capacity still need increases 300X

Capacity= \#sector*BW*Spectrum Efficiency
Cost Challenge: Decreasing the bit transmission Cost

Gross profit = (ARPU - Monthly Traffic Volume*MB Unit cost) / (Monthly Traffic Volume*MB Unit cost)

Busy Hour Traffic Volume

Volume in one day

BHR: traffic in busy hour / traffic in one day

MB yte TCO = \( \frac{\text{site TCO per day}}{\left( \text{BW} \times \text{Spectrum eff} \times 3600 \right) / \text{BHR}} \)
Experience Challenge: Sustained QoE/QoS

Superlative experiences will win customers

Small volume, but low delay
Challenge in network delay

Latency of network less than latency of Human response (117ms)

Visual: 150ms
Touch: 117ms
Hear: 120ms

摘自人体反应时研究文档
Energy Challenge

• Global scale:
  • Energy consumption of ICT not neglectable (2% of CO2-emission)
  • 3G Basestation example
    • RF output @antenna: 60W
    • Power input: 1000W (Efficiency 6%)
    • Design for spectrum efficiency, Not Power efficiency
  • Electricity Bill
    • 1W*1year = 8.6 KW*h
    • 1,000,000 BS in China

Not forget battery of device

- Historical 11% capacity growth
- Not well matched to Moore’s Law
- Continued innovation required just to maintain 11%
- New Si alloy materials or anode Carbon Nano Tubes (CNT) may help

<table>
<thead>
<tr>
<th>2011</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Today</td>
<td>11% Growth</td>
</tr>
<tr>
<td>mWH</td>
<td>5700</td>
</tr>
<tr>
<td>1 day</td>
<td>475mW</td>
</tr>
<tr>
<td>3 day</td>
<td>159mW</td>
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Assuming 12 hours of use per day
Driving Transformation

Only by meeting challenges will we realize new opportunities

- Develop Cloud based services
- Increase 500x capacity and more
- Expand all encompassing mobility
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Spectrum Efficiency

![Chart showing spectral efficiency improvements over decades.](chart.png)

**GAP**

- **GSM**: 0.1
- **EDGE**: 0.3
- **HSPA**: 0.5
- **LTE**: 1.2
- **EASY-C**: 3
- **Theory**: 10

1987 → 20 Years → 2007 → 20 Years

**Equation**:

\[ C_{MIMO} = M f_t \log_2 \left(1 + \frac{S}{N}\right) \]
HetNet: A Key for 500x Capacity

- Flat architecture
- QoS Focused

1 - 5x

10 - 50x

100 - 500x
Hyper Transceiver

• Definition:
  – All transmitters jointly transmit signals
  – All receivers jointly decode received signals

• In cellular system, if UEs do not exchange information
  – For UL, all BSs jointly decode all UE’s transmission → Hyper Receiver
  – For DL, all BSs jointly encode all UE’s transmission assuming known UE’s channel knowledge (for example, DPC) → Hyper Transmitter

• When UE can share the info, e.g., via D2D (WiFi), true hyper transceiver is feasible

• With distributed BS architecture, JP CoMP is a form of Hyper Transceiver

• Combining centralized network architecture (such as C-RAN, BBU hotel) with D2D cooperation, Hyper Transceiver could be the key enabler to optimize spectrum efficiency
Theoretical Capacity of Hyper Transceiver

Cellular system without UE cooperation

Large potential exists for spectrum efficiency enhancement with Hyper Transceiver, key challenge is how to realize it practically

$\eta$: Path Loss Exponent
BS transmit power: 50W
UE Transmit power: 200mw
16 UE Per cell

DL: 2.5 bit/s/Hz, 2x2
UL: 1.6-1.8 bit/s/Hz, 1x2
Known Ingredients

- MU-MIMO
- Interference Alignment
- Dirty Paper Coding
- Successive Interference Cancellation
- CoMP
Sum capacity performance of MU-MIMO with the number of users = number of antenna = 4 for the Grassmanian, random and 3GPP LTE base codebooks.
MU-MIMO Issues

- **DL MIMO**
  - Rel-8 codebook design is far from optimized
  - Codebook optimized for linear array type of antennas
  - Limited resolution due to feedback overhead consideration
    - Implementation complexity for user paring
    - Neighboring cell Interferences limit SINR, hence limit the gain
    - The number of antennas for one BS is limited

- **UL MIMO**
  - Limited number of receive antennas for one BS
  - Neighboring cell Interferences limit SINR, hence limit the gain
  - SIC receiver complexity
DL CoMP

- DL CoMP candidate technologies mainly target CL transmission scenarios where power domain cooperation transmission is less effective.
  - DL Coordinated MIMO
- From power domain coordination to spatial domain coordination
  - CBF and CBS
- From single cell MU-MIMO to multiple cell MU-MIMO
  - CBF, JP
- From single point transmission to multiple point transmission
  - JT
Overview of DL CoMP Performance (4 Tx ULA)

- 1. FFR4-OL
- 2. FFR4-CL
- 3. CBS-rank1
- 4. CBF intra
- 5. CBF inter
- 6. CBF+AC+FFR4
- 7. Intra SU JP
- 8. Inter SU JP
- 9. MRC MU-MIMO non-JP
- 10. MRC intra MU-MIMO JP
- 11. IRC1 MU-MIMO non-JP
- 12. IRC1 intra MU-MIMO JP
- 13. IRC1 inter MU-MIMO JP
- 14. IRC1 MU-MIMO JP

SU-MIMO, MU-MIMO with AC feedback
Performance comparison of different IC/MRC techniques

Ideal channel estimation (CE) and ideal IC

- Vi IC/MRC does not provide extra gain compared to local IC/MRC while Vi IC requires extra backhaul traffic to transfer information of local UE to serving cell.
- No IC/MRC, local IC/MRC and local IC + C2C IC/MRC are the reasonable candidates.

**Diagram Notes:**
- No IC
- Local IC
- Local IC + C2C IC
- Vi IC
- Vi IC + C2C IC
- C2C IC
- Global IC

**Graph:**
- X-axis: Sum Throughput Gain [%]
- Y-axis: Cell Edge Throughput Gain [%]
Impact of imperfect CE/IC on performance

IC/MRC techniques

- Big gap between performance with ideal and non-ideal channel estimation
- Room to improve PHY detection techniques for future work

It is assumed that non-ideal IC leaves 30% of power of interferer on target signal

Local: IC of local UE @ coop
Vi: IC of local UE @ both cells
C2C: IC of CoMP UE @ coop
Network MIMO的支撑技术

- Network MIMO需要中心处理（CP），BS到CP数据传输及AP到BS的传输成为关键问题
  - Fiber
  - DF（Decode-and-Forward）
  - CF(Compress-and-Forward)
  - 混合模式？
Green Radio: Insight from Shannon

- Green Radio
- Spectrum Efficiency
- Energy Efficiency
- Cost
- Deployment Efficiency
- Bandwidth
- Power
- Average Power
- Average Delay
Guidelines for Energy Efficiency Radio Access Network Design

- Optimal cell size for network planning
- Target Deployment budget
  - Target cell edge user rate
- Target Deployment efficiency

**Curves of DE-EE Relations**

- Energy efficiency vs cell size
- Only Tx power considered
  - Matches our intuition
- Static power and circuit power also considered
  - Deviates our intuition

- Deployment Efficiency (bits/s/J)

```
x 10^{-4}
```

```
x 10^{-3}
```

```
x 10^{-4}
```
- Mobile Storage rapidly increasing, lower cost (Flash <1$/GB).
- Always connected and everything stored centrally OR Everything in devices?
- New storage based system paradigm
- CONA is a networking architecture optimized for content storage and dissemination, the most similar works with CONA is the CCN (led by Van Jacobson) and EU FP7 4Ward NetInf.
- Basic idea is Content naming and Routing.
Thank you

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