pCell Technology: Delivering 5G-grade Performance to 4G LTE Devices

IEEE Communication Theory Workshop
May 16th, 2016

Antonio Forenza, PhD
Co-founder & CTO, Artemis Networks
• Background
• pCell: how it works
• SDR wireless platform
• Experimental results
• Conclusions
Global Mobile Data Traffic (Actual/Projected)

CAGR = 40-70%

• 3 solutions [Qualcomm, SKT, Nokia]
  • More cell density
  • More spectrum
  • More spectral efficiency

“New forecasts show much more spectrum is needed.”

“Operators will continue to deploy new cells, including small cells, and will continue to upgrade networks to state-of-the-art 4G LTE technology to take advantage of improved spectral efficiency, but that is not enough.”

More Cell Density

- Small cells perform poorly
  - Intercell interference [Andrews’15]
  - Handoff overhead [3GPP-TR36.839]
- Solutions
  - SON and ICIC [AT&T’12][Mao’08]
  - CoMP [3GPP-TR36.819][ChinaMob’11]
- High cost, difficult deployment
  - Zoning permits
  - Backhaul

“AT&T has dropped plans to deploy 40,000 small cells on its network by the end of 2015”

Fierce Wireless, March 2015
• National Broadband Plan [FCC’10]
  • 547 MHz available in 2010 for mobile broadband
  • Allocate 500 MHz by 2020

• LTE-U [Forum’15][Qualcomm’15]
  • Operate LTE in ISM unlicensed 5GHz band
  • Use 200 MHz of spectrum (+300 MHz for future use)

• Millimeter-wave [Rappaport’14]
  • Pros: large bandwidth [Heath’16]
    • BW=4GHz @ 28 and 38 GHz
    • BW=7GHz @ 60 GHz
  • Cons: pathloss, body absorption (blocking)
  • Short-range links, up to 200m
  • Applications: WiGig fronthaul [Facebook’16]
More Spectral Efficiency

- **Massive-MIMO**
  - Theory: asymptotically noise/interference-free links [Marzetta’10][Larsson’14]
  - Requires upgrade to 4G LTE standard, proposed for Pre-5G [3GPP-Rel.13]
  - Practical only at mmWave, complex RF design
  - Centralized cellular architecture
    - Pilot contamination
    - Coordination between cells
  - 4-8x mux gain with 64-128 antennas [ZTE’16][Intel’16]

- **pCell**
  - Theory: [Caire’03][Viswanath’03][Yu’04][Foschini’06]
  - Compliant with standard LTE Rel.8 devices, readily deployable
  - Works at any frequency band, simple frequency-agile RRHs (pWaves)
  - Distributed architecture, no cells
  - 16x mux gain with 24 antennas, can scale to higher orders
Downlink Spectral Efficiency

5 MHz, 2-antenna LTE devices

Presented results

pCell Performance Today

[Spectral Efficiency (bps/Hz)]

1.2 bps/Hz per sector
1.7 bps/Hz per sector

HSPA+ LTE pCell

59.3 bps/Hz per area ≥1 m²

[1.2 bps/Hz]

Rysavy Research/4G Americas, August 2014

May 16, 2016
Patents, Patents Pending
Page 8
• Background
• pCell: how it works
• SDR wireless platform
• Experimental results
• Conclusions
Cellular vs. pCell Coverage

- **Cellular Coverage**
  - Base Station
  - User Equipment
  - Power distribution

- **pCell Coverage**
Benefits of pCell
- High spectral efficiency (spatial multiplexing gain)
- Consistent data rate, no cell-edge (macro-diversity)
- No inter-cell interference
- No handoff overhead
- No near-far problem
- PHY-layer security
- Precise location positioning

- 500mW
- 20MHz TDD
- Max 256-QAM
SINR Analysis

• System and channel models: \( N \) transmitters, \( U \) users

\[
y = Hx + n \quad y \in \mathbb{C}^{U \times 1}
\]

\[
x \in \mathbb{C}^{N \times 1}
\]

\[
H \in \mathbb{C}^{U \times N}
\]

• Volume of coherent signal [Artemis’15]

\[
\mathcal{V}_u(\text{SINR}_o) = \{ \vec{r}_u + \vec{r}; \text{SINR}_u(\vec{r}) \geq \text{SINR}_o \}
\]

• Radius of volume of coherent signal

\[
R_u(\vec{r}) \approx \frac{\lambda}{2\pi \sqrt{\sum_{s < t} \xi_{us}\xi_{ut} (\cos \gamma_{us} - \cos \gamma_{ut})^2}} \sqrt{\frac{1}{\text{SINR}_o} - \frac{1}{\text{SNR}_u}}
\]
Centralized transmitters
(ULA with $\lambda/2$ spacing)

$N = 10$, $U = 8$

Distributed transmitters
Volumes of Coherent Signal

\[ N = 16, \quad U = 10, \quad \text{SINR}_o = 5 \text{dB} \]
• Background
• pCell: how it works
• SDR wireless platform
• Experimental results
• Conclusions
Hardware Architecture

Internet → pCell Data Center

Internet

pCell Data Center

Fiber x n → Line of Sight

Line of Sight → GigE PoE switch

GigE PoE switch

GigE → Artemis Hub

Artemis Hub

32 x Coax → Antennas

Antennas

Fiber

Fiber

Fiber pWave

GigE

GigE

GigE pWave

GigE pWave

LTE UE
Software Architecture

pCell Data Center

Internet

IP Routing

VRI 0 eNB
VRI 1 eNB
VRI 2 eNB
VRI 3 eNB
VRI 4 eNB
VRI 5 eNB
VRI 6 eNB
VRI 7 eNB

pCell Processing

Fronthaul

A
B
C
D
E
F
G
H

pCell antenna
LTE UE
pCell
TDD LTE Frame

SRS 1
SF #0  SF #1  SF #2  SF #3  SF #4  SF #5  SF #6  SF #7  SF #8  SF #9
DL | DwPTS (DL) | UL | DL | DL | DL | DwPTS (DL) | UL | DL | DL

1 msec
• Background
• pCell: how it works
• SDR wireless platform
• Experimental results
• Conclusions
Indoor Trials

- Patch antennas
  - 8 dBi, HPBW=75°

- Cart with 16 iPhone 6 Pluses in 1 m²

- Artemis I Hub
  - 1 mW RF output at 1.9 GHz in 5MHz

May 16, 2016

Patents, Patents Pending
16 iPhone 6 Pluses in 1 Square Meter

1m x 1m Plexiglass table
Measured LTE MAC-level SE

Downlink (Avg. 59.3, Peak 59.8 bps/Hz)

Uplink (Uniform Peak: 27.5 bps/Hz)
• Rooftops in downtown SF
  • 600 rooftops available
  • 58 rooftops for first trial
  • About 500 pWaves for beta-testing
• Wireless synchronization
• 600 to 6000 MHz
• 0.5 to 5W EIRP
• PoE+ or Fiber
pWave Installations

LTE Antennas
Frequency-agile RRH
Fiber, power
• Background
• pCell: how it works
• SDR wireless platform
• Experimental results
• Conclusions
Conclusions

• Higher SE is the practical solution to “spectrum crunch”

• Distributed antennas enable confined volumes with peak SINR

• Volumes for multiple users yield large spatial multiplexing gain

• Large multiplexing gain with a deployable SDR wireless platform

References

- [Facebook’16] The Verge, “Facebook’s new gigabit Wi-Fi system is coming to San Jose”, Apr. 13th, 2016 http://www.theverge.com/2016/4/13/11410818/facebook-terragraph-gigabit-wifi-millimeter-wave
- [ZTE’16] “ZTE wins two awards at MWC”, Feb. 2016 https://www.youtube.com/watch?v=tO1a6ESsO5w
Thank you