Potential of Multi-band Heterogeneous Cellular Networks and their Performance Boosting Technologies

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Contents

- Challenging issues in Mobile Networks
- Multi-band heterogeneous networks (HetNet)
- Cloud cooperated multi-band HetNet
  - Data / control plane splitting & seamless handover
  - Centralized dynamic pico-BS resource control
  - Virtual cell structuring by cloud cooperated CoMP
- Summary & future perspective

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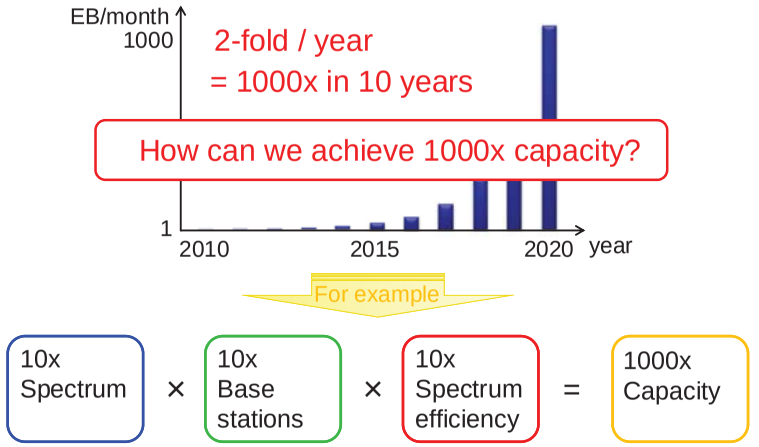
Mobile Traffic Explosion

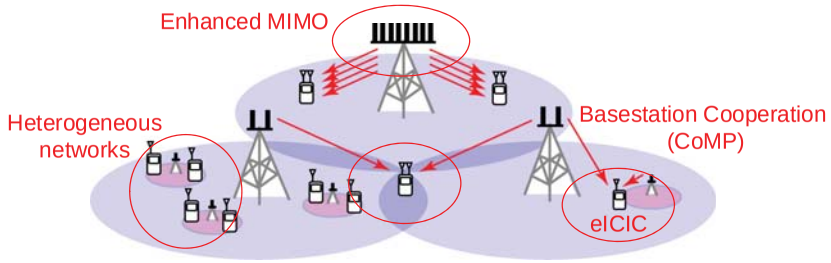
Mobile data traffic forecast



4G Cellular Networks

- MIMO enhancement to improve average spectral efficiency
- CoMP to improve outage rate
- Heterogeneous network for traffic offloading
- New frequency band (3GHz, 60GHz) to enhance bandwidth

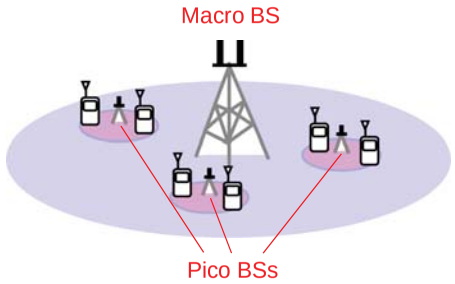
Focus of MiWEBA workshop

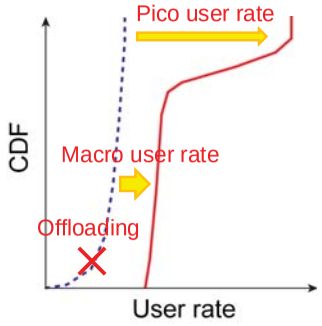


Contents

Heterogeneous Network

- Deploy pico BSs within macro-cell
- Improve user rate near the pico-BS
- Improve system rate by macro user offloading





Multi-Band HetNet

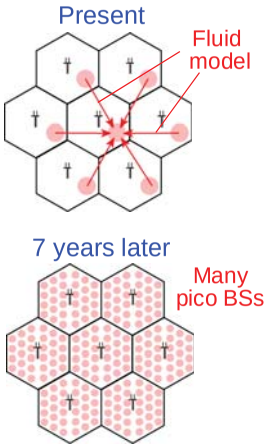
- Macro-pico interference management is necessary
- Spectrum splitting loss occurs in single-band HetNet（e.g. ABS）
- Multi-band HetNet achieves BW enhancement without interference

Single-Band	Multi-band	
2GHz band	3GHz band	60GHz band
Macro：	Macro：	Macro：
Center freq: 2GHz	Center freq: 2GHz	Center freq: 2GHz
BW: ρ×10MHz	BW: 10MHz	BW: 10MHz
Tx power: 46dBm	Tx power: 46dBm	Tx power: 46dBm
Pico：	Pico：	Pico：
Center freq: 2GHz	Center freq: 3.5GHz	Center freq: 60GHz
BW: (1-ρ)×10MHz	BW: 100MHz	BW: 2.16GHz
Tx power: 24dBm	Tx power: 30dBm	Tx power: 10dBm

Condition of Analysis

- System rate improvement vs. number of pico BSs
- Consider three traffic load cases（present, 7 years later, 17 years later）

Macro BS	Center freq.	2GHz
	BW	10MHz
	Tx power	46dBm
	ISD	500m
3G pico BS	Center freq.	3GHz
	BW	100MHz
	Tx power	30dBm
60G pico BS	Center freq.	60GHz
	BW	1GHz
	Tx power	10dBm
Metric	User rate	≤8bps/Hz × BW/coverage area
Traffic	Present, 7 years later, 17 years later	1kbps/m^2,100kbps/m^2,100Mbps/m^2
Propagation model	Path loss (PL)	Distance-dependent PL exponent：3, Frequency exponent：2
	Interference model	Fluid model



Optimization of Cell Range

- Pico-cell range controls tradeoff between pico-UE rate and offload effect
- Optimization of pico-cell range to mazimize system rate (sum of BS rates)

Cell coverage & average BS rate

$$A_{Pi}: (x-x_i)^2+(y-y_i)^2 \le r^2$$

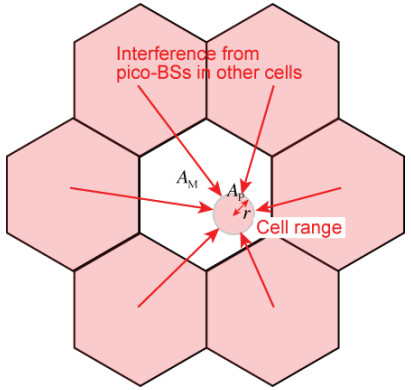
$$A_M = \overline{A_{P1} \cup A_{P2} \cup \cdots \cup A_{PN_P}}$$

$$R_{Pi}(r) = \iint_{A_{Pi}} \min\left(\frac{C_P}{|A_{Pi}|}, L\right) dA$$

$$R_M(r) = \iint_{A_M} \min\left(\frac{C}{|A_M|}, L\right) dA$$

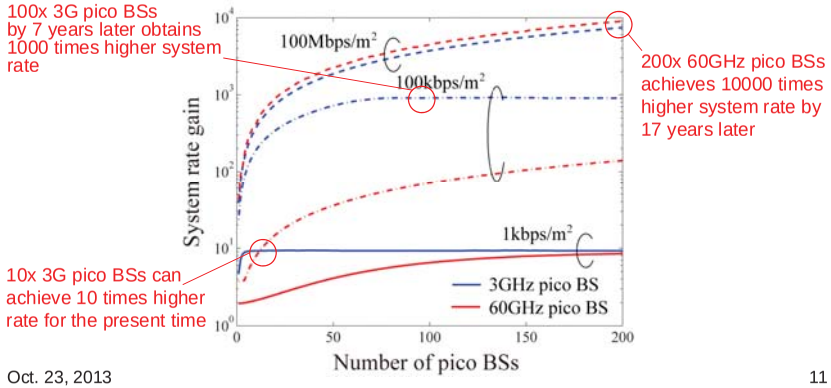
Optimization of pico-cell range

$$r^* = \arg\max_r \left(R_M(r) + \sum_{i=1}^{N_P} R_{Pi}(r) \right)$$



Preliminary Results

- 1000 times higher rate by installing 100x 3G pico BSs by 7 years later
- 3G pico BSs are beneficial when user traffic is low
- 60GHz pico BSs are beneficial in case of high user traffic and/or hotspots



To Realize Multi-band HetNet

- Efficient pico-cell discovery
  - UE with dual connectivity is necessary for multi-band HetNet
  - Power efficient pico-cell discovery is challenging issue for sparsely deployed pico-cell scenario
  - Seamless handover between pico-macro and pico-pico is challenging issue in densely deployed pico-cell scenario
- Dynamic operation of pico-BS
  - To overcome the limited coverage, dynamic operation of pico-BS is necessary to match the location & traffic of UE
  - Dynamic optimization of pico-BS parameters (tx power, beam angle, cell range, etc.) is challenging issue to maximize system rate
  - Dynamic pico-cell structuring to track time variant location of hotspot is challenging issue

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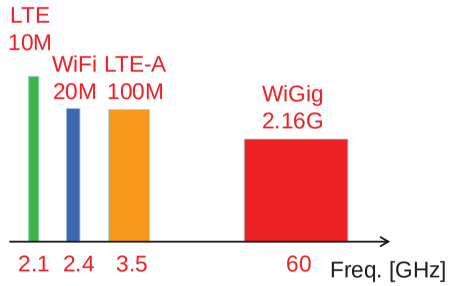
Dual Connectivity & Cell Discovery

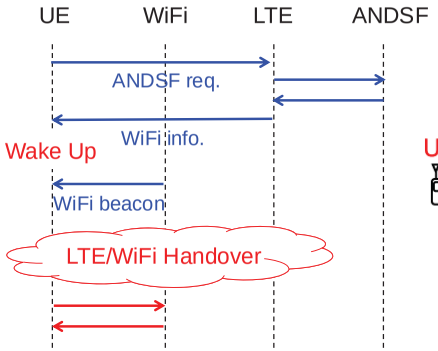
- Single connectivity UE cannot perform data commun. & cell discovery at the same time
- UE with dual connectivity is necessary for multi-band HetNet
- Tradeoff between power consumption & connection delay (e.g. several seconds) for pico-cell discovery

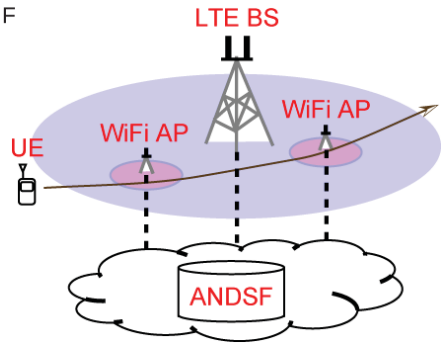
@ apple co.



ANDSF (Access Network Discovery & Selection Function)

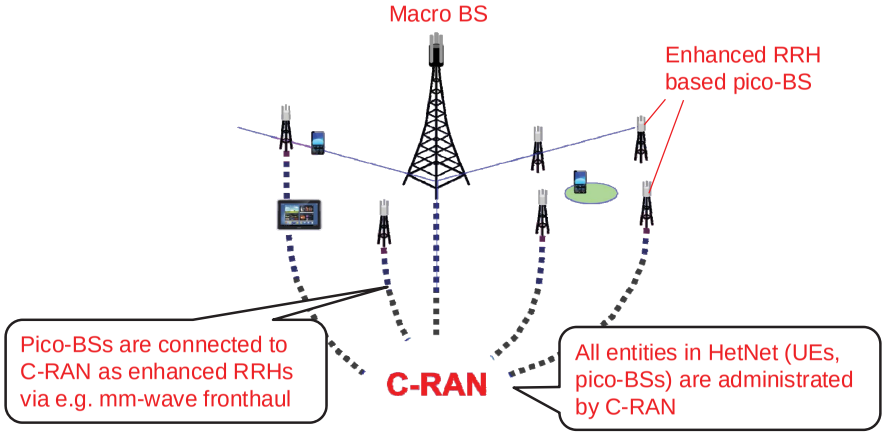
- Cell discovery assisting function for WiFi standardized in 3GPP
- Location based WiFi UE wake-up by using AP database in ANDSF server
- Power saved inter system handover between LTE & WiFi





Cloud Cooperated HetNet

- Integrate pico-BSs as RRHs of C-RAN based macro cellular network
- C-RAN acts as commander of HetNet to accommodate traffic explosion



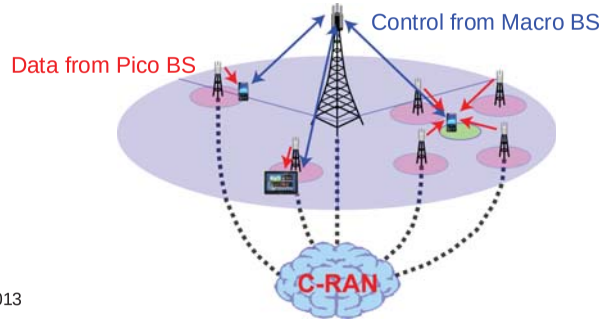
Data / Control Plane Splitting

Heterogeneity on System (Freq.)
e.g. LTE & WiFi

Heterogeneity on Coverage
e.g. Macro & Pico

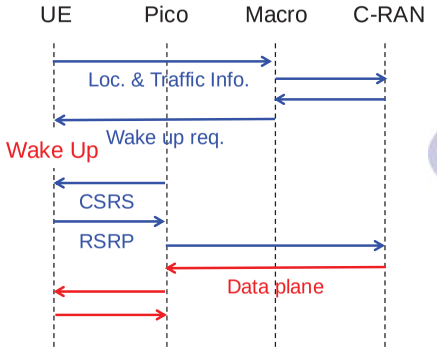
Heterogeneity on Role (data / control plane splitting)

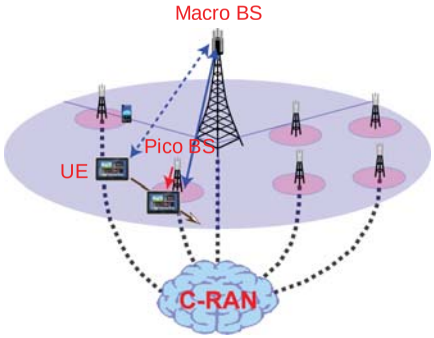
- Control plane from macro-BS where connectivity is most important
- Data plane from pico-BS where transmission rate is most important



Seamless Handover

- Macro assisted centralized handover based on UE location & traffic load
- Location based UE pico-link wake-up by using C-plane on macro-link
- Power saved & short delay (data only) intra system handover





Dynamic Pico-BS Resource Control

- Dynamic control of pico-BS parameters (tx power, tilt angle, cell range) via C-RAN for power saving, effective offloading, and interference control
- System optimization (sum average/outage rate) by using measurement report (RSRP, SINR, traffic load)

Cell association

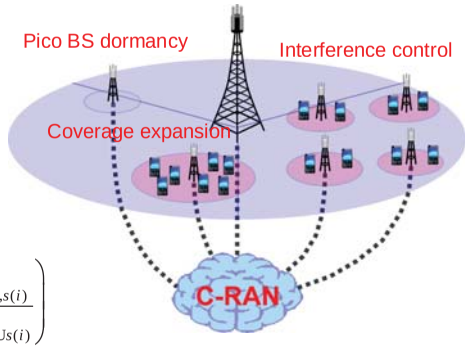
$$s(i) = \arg\max_j C'_{i,j}$$

$$C'_{i,j} = \begin{cases} C_{i,j}, & j = 0 \\ C_{i,j} + \alpha_j, & j = 1, \cdots, N_{\mathrm{p}} \end{cases}$$

Resource optimization

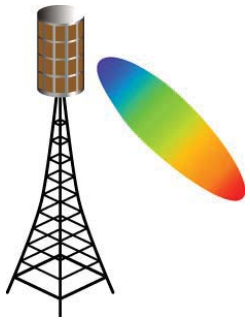
$$\left\{ p_1 \cdots p_{N_{\mathrm{p}}}, \quad \theta_1 \cdots \theta_{N_{\mathrm{p}}}, \quad \alpha_1 \cdots \alpha_{N_{\mathrm{p}}} \right\} =$$

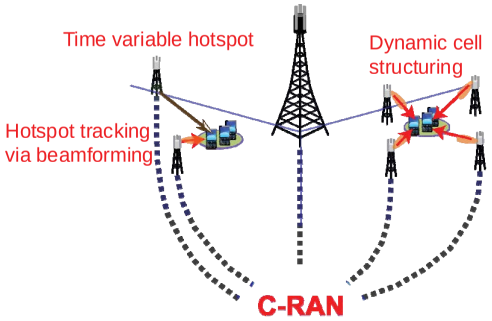
$$\arg\max_{\mathbf{p},\, \theta,\, \alpha} \left(\sum_{\forall s(i)=0} \frac{C_{i,s(i)}}{N_{\mathrm{Us}(i)}} + \sum_{\forall s(i)=1 \cdots N_{\mathrm{p}}} \frac{C_{i,s(i)}}{N_{\mathrm{Us}(i)}} \right)$$



Dynamic Pico-BS Beam Control

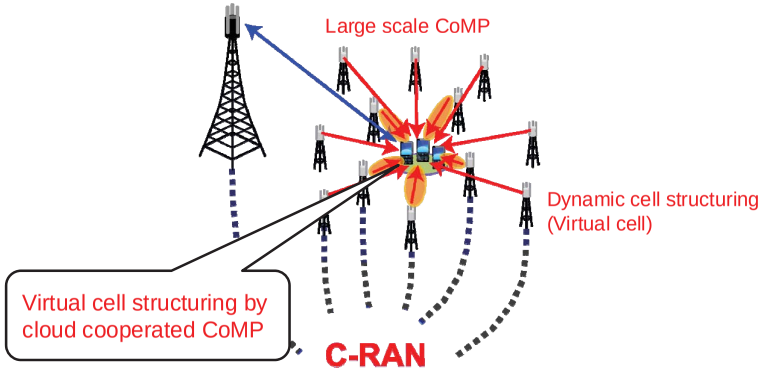
- Beamforming antenna or massive MIMO forms free style pico-cell
- Dynamic cell structuring to track time variant location of hotspot
- Effective for pico-BSs using high frequency such as mm-wave





Cloud Cooperated CoMP

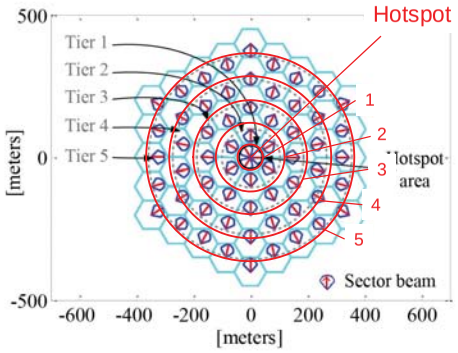
- Create virtual cell of cooperative pico-BSs based on location of hotspot
- Concentrate power of all pico-BSs to hotspot via dynamic beam control
- System rate enhancement by large scale MU-CoMP of pico-BSs



Condition of Analysis

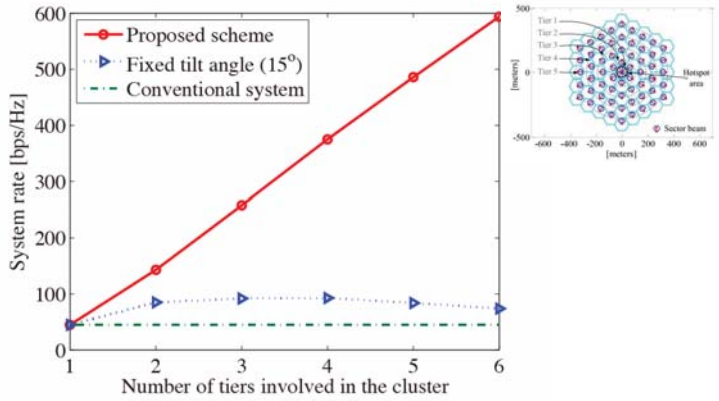
- Evaluate effectiveness of dynamic cell structuring in single hotspot scenario
- System rate of large scale CoMP vs. number of tiers in the cluster (pico-BSs)

Frequency	3.5GHz
Transmit power	30dBm
Inter-site distance	100m
# of pico-BSs	3, 9, 21, 39, 63
Horizontal beam width	70°
Horizontal beam angle	Dynamic
Vertical beam width	10°
Vertical tilt angle	Dynamic, 15° (fixed)
BS height	5m
# of UE / cell	30



Results of Analysis

- Drastical performance improvement by increasing the number of tiers
- Linear increase of system rate by dynamic cell structuring (beam control)



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Summary & Future Perspective

Explosion of mobile traffic

Multi-band HetNet is indispensable

Efficient operation of HetNet via cloud cooperation

- Power saved & seamless handover via data / control plane splitting
- System rate maximization via centralized dynamic resource control
- Virtual cell structuring to track hotspot by cloud cooperated CoMP

Future Perspective

- New role of cellular networks as a commander of other wireless systems
- Development of scalable HetNet (Cellular / WiFi, WiFi / mm-wave, etc.)
- Establish new forum to realize 5G multi-band HetNet