# Adaptive Antennas for Wireless Communications

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17th International
WSA 2013
ITG Workshop on Smart Antennas
13-14 March 2013, Stuttgart, Germany

# Adaptive Antennas for Wireless Communications

outline:

mobile data growth and the need for adaptive antennas

adaptive antenna concepts and aspects

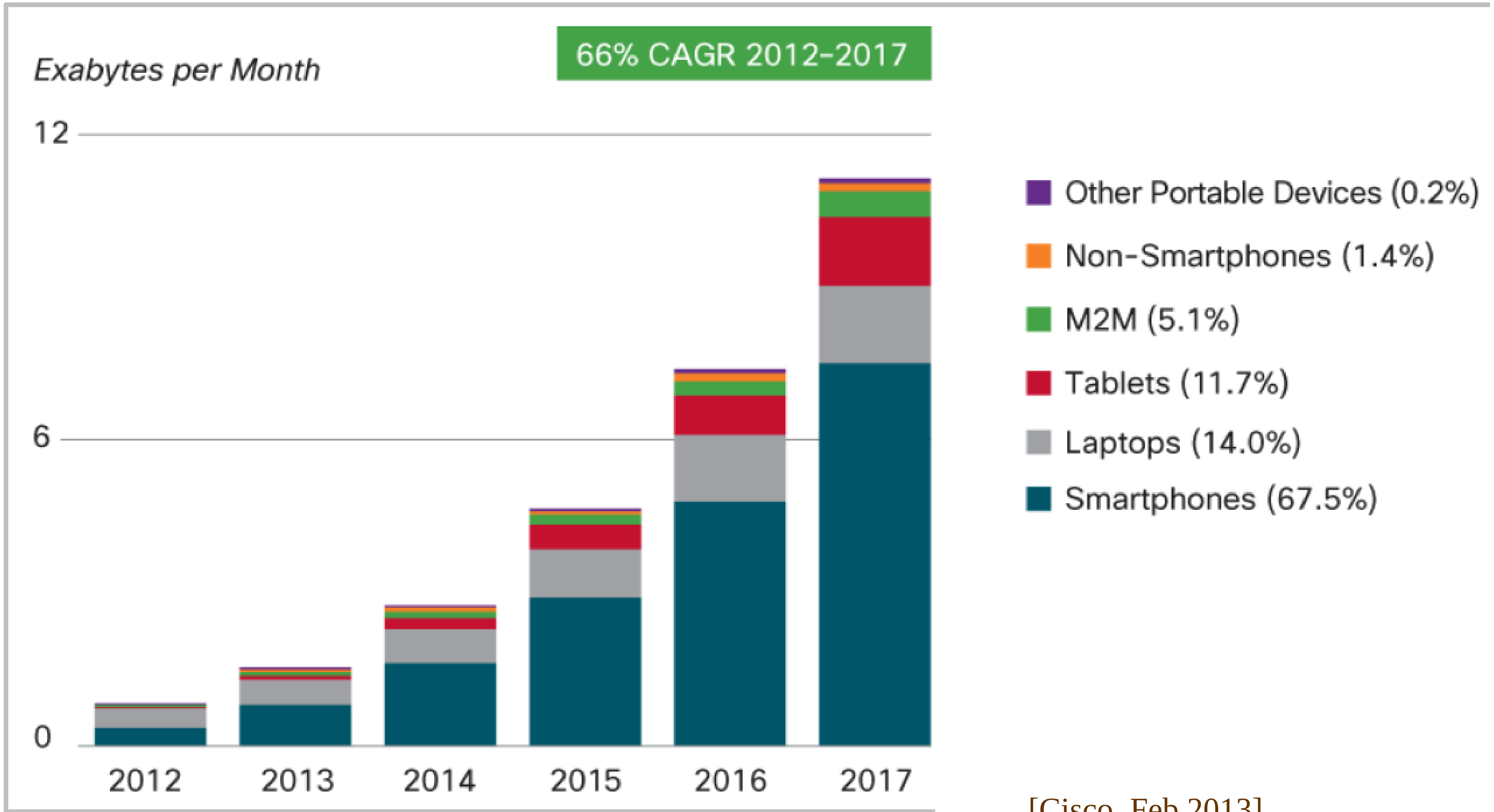
- cellular base station / microwave adaptive antennas
  - . wide-angle azimuth beam steering
  - . frequency-selective elevation beam steering
  - . broadbanding / frequency adaptivity
- point-to-point / millimeter-wave adaptive antennas
  - . small-angle $\theta$ & $\varphi$ beam steering
  - . wide-angle azimuth beam steering
  - . wide-angle $\theta$ & $\varphi$ beam switching

conclusion

# exponential growth of wireless data traffic volume

mobile data volume grows with CAGR of ~ 40…70% [various sources]

i.e., increase by factor of 10…40 until 2020




[Cisco, Feb 2013]

# solutions for tackling the problem of wireless data growth

*possible capacity increase for the next decade [my guess]:*

**more frequency bandwidth**

… can millimeter-wave be an option? (LOS!) … or infrared ?

… but: not much left „unused“ between 0.7 and 2.8 GHz — *x 2*

… cognitive radio (frequency sharing) is „promising“ — *x 2*

**more clever coding**

… cognitive radio (frequency sharing) is „promising“

… but: today‘s algorithms are close to Shannon‘s limit — *x 2*

**less power per user**

… lower power, i.e., shorter range, i.e., small cells & het nets — *x 10…100…*

→ adaptive antennas come into play here

# wireless mobile versus nomadic

not all cellular traffic is „mobile“:

- 50% of all traffic generated in 1 cell[1].
- 80% data traffic carried by 3 cells[1].
- Remaining 20% carried over 28 cells.

[Detecon 2012 ]

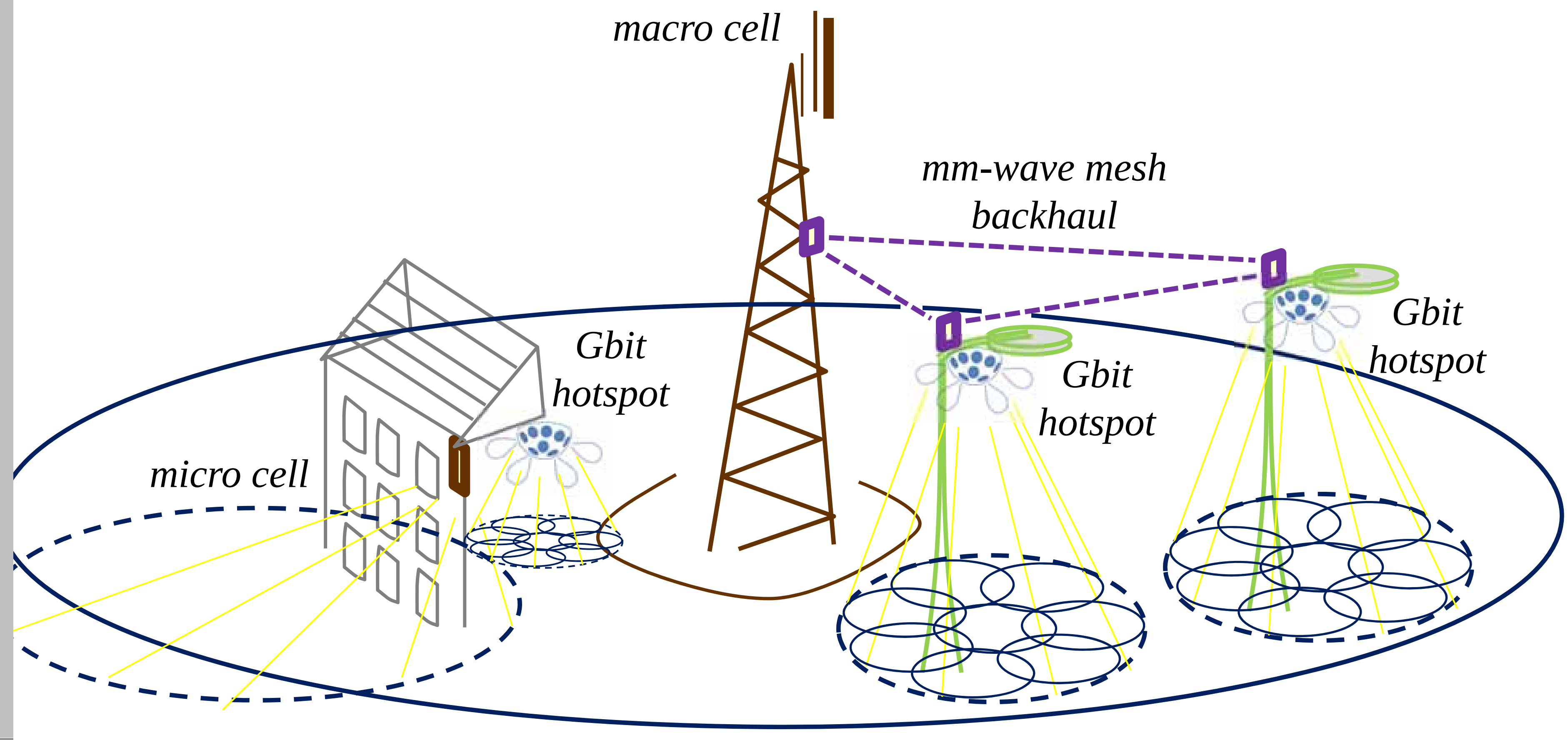
→ off-loading of data hot spot traffic in small cells makes sense

. consequences for signalling,
Doppler,
pricing

the resulting network consists of different kind of wireless installations:

. wide-area coverage using macro-cells and micro-cells
. hot-spot (nomadic) secondary coverage using pico-cells
. hot-spot backhaul using mm-wave point-to-point links
. hot-spot (fixed) GBps-coverage using LOS-hubs (mm-wave, infrared)

# the wireless network




. wide-area coverage using macro-cells and micro-cells

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# different needs for antenna adaptivity

wide-angle azimuth
beam steering

frequency-selective
elevation beam steering

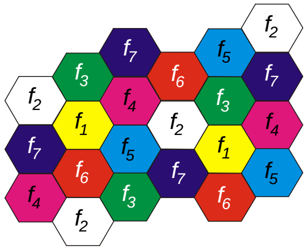
broadbanding
/ frequency adaptivity

small-angle θ & φ
beam steering

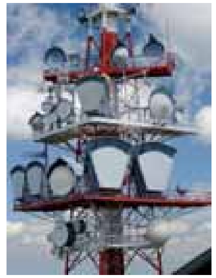
wide-angle azimuth
beam steering

wide-angle θ & φ
beam switching

**cellular**




**point-to-point**



[wikipedia]

$f$

0.3 — 3 — 30 — 300 /GHz

*low gain (< 20 dBi), wide band (> 15%) antennas*

*high gain (> 20 dBi), narrow band (< 15%) antennas*

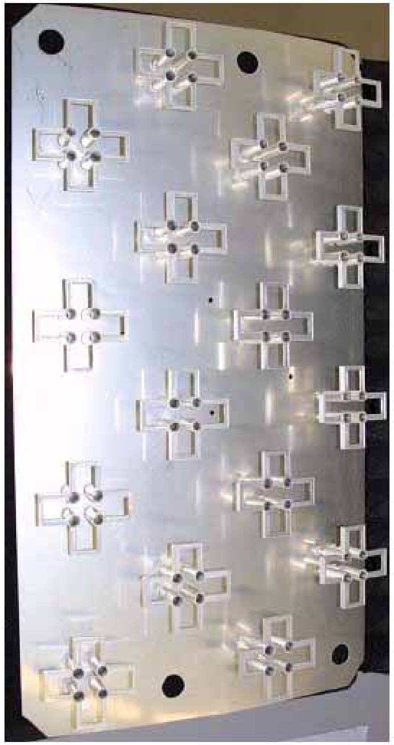
*low freq backhaul? probably not*

**???**

*mm-wave cellular? probably yes*

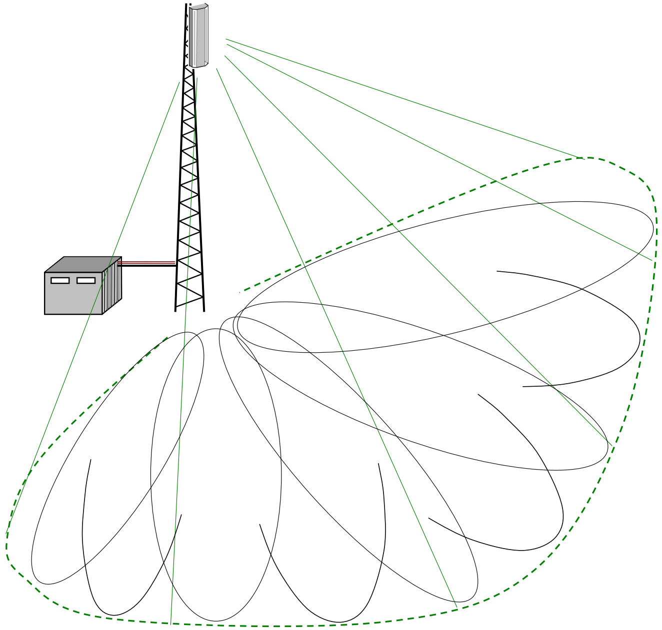
# wide-angle azimuth beam steering for cellular:

- for large-area coverage using macro-cells
- results in large form-factor antennas
- RF issues: form factor, weight



→ weight issue addressed:
4 column dual-pol array
1710-2170 MHz (-14 dB)
metalized plastic +
carbon composite structures

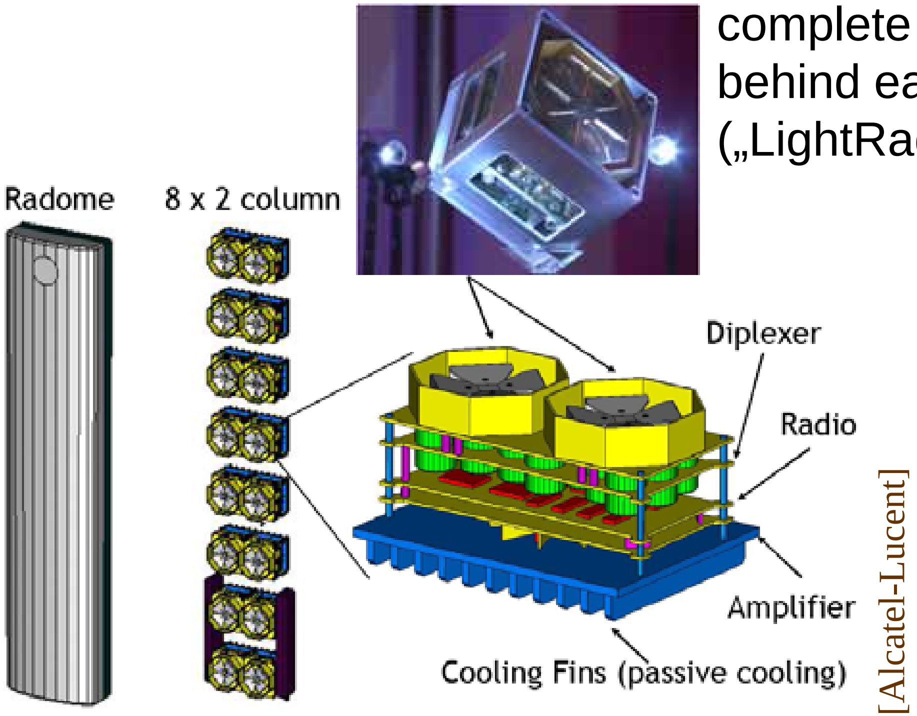
[Huber+Suhner]



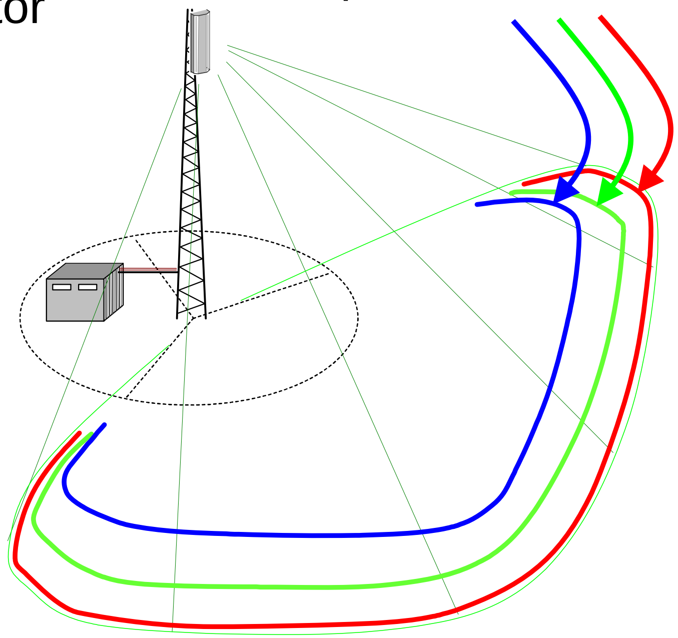
# frequency-selective elevation beam steering for cellular:

- for large-area coverage using macro-cells
- requires active radios behind each radiator in the antenna column
- RF issues: bandwidth, phase-front calibration, flexibility, weight

complete TX/RX-chain behind each radiator („LightRadio“)

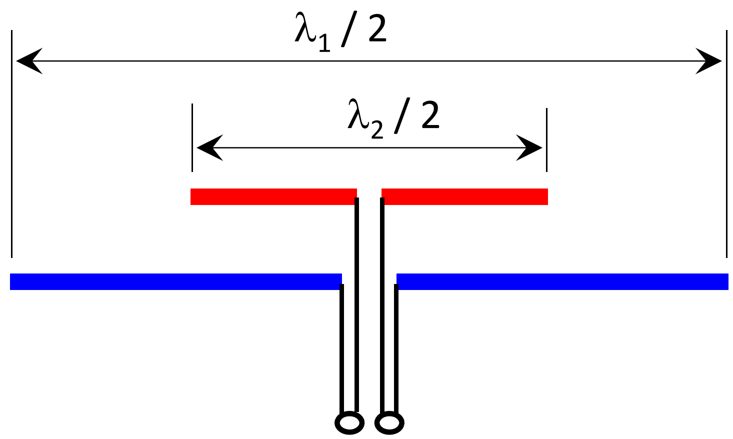



different tilt/footprint for different channels/ frequencies/UL-DL



# broadbanding / frequency adaptivity for cellular:

- multi-band cellular covers up to 4:1 frequency range (700…2800 MHz)

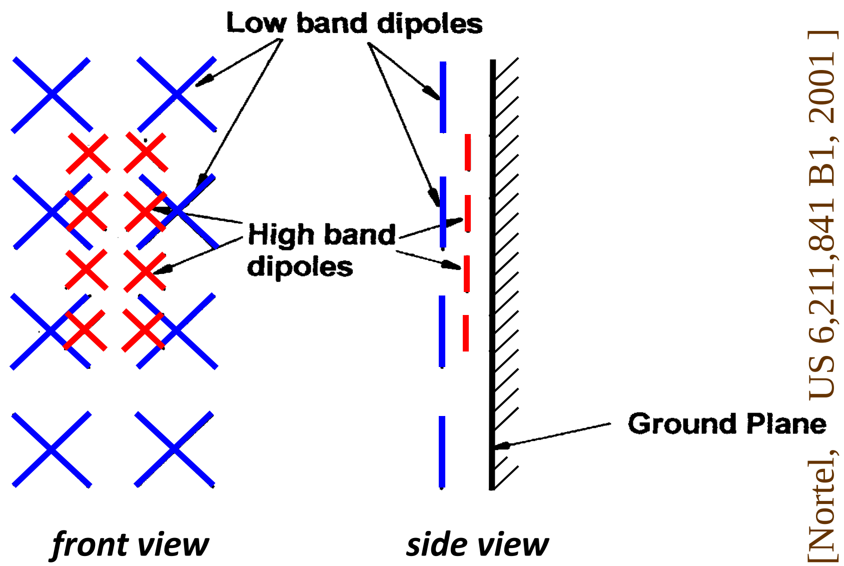



- stacked dipoles / stacked crossed dipoles / stacked patches can cover multiple bands

- however element spacing in an array should scale with frequency, too

- interlaced arrays are geometrically complex and prone to high cross-polarization, particularly for non-integer frequency ratios

→ solution: connected array

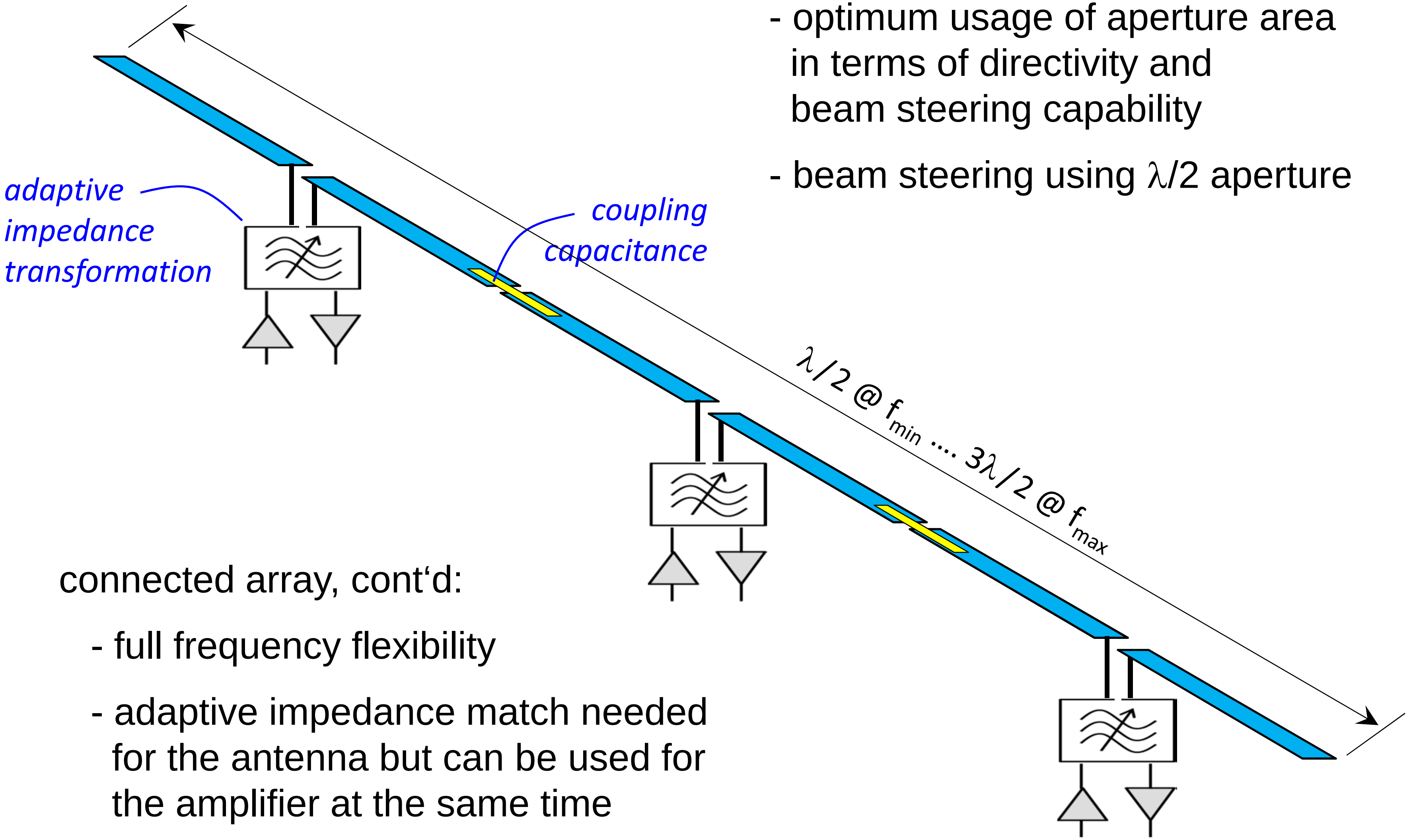



[Nortel, US 6,211,841 B1, 2001 ]

# broadbanding / frequency adaptivity for cellular:

use of connected array principle:

- optimum usage of aperture area in terms of directivity and beam steering capability
- beam steering using λ/2 aperture




connected array, cont'd:

- full frequency flexibility
- adaptive impedance match needed for the antenna but can be used for the amplifier at the same time

# small-angle θ & φ beam steering for mm-waves:

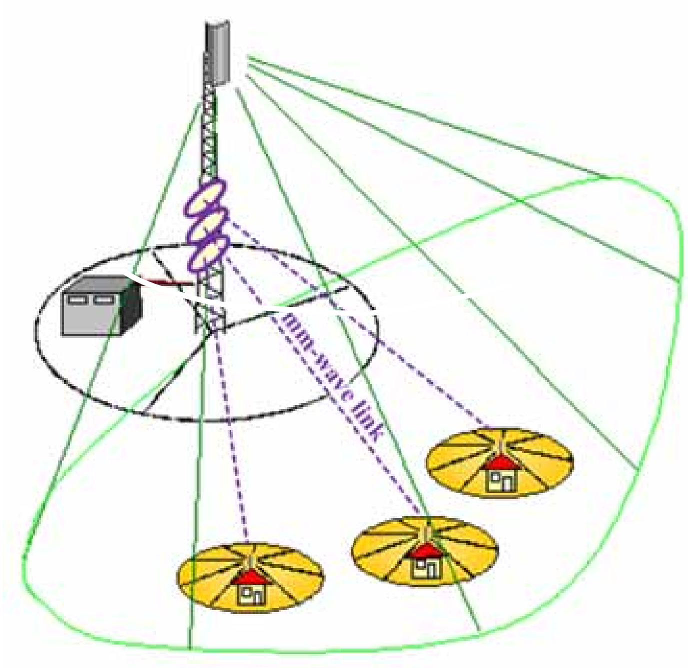
long-distance mm-wave backhaul requires high-gain parabolic dish antennas and very careful alignment

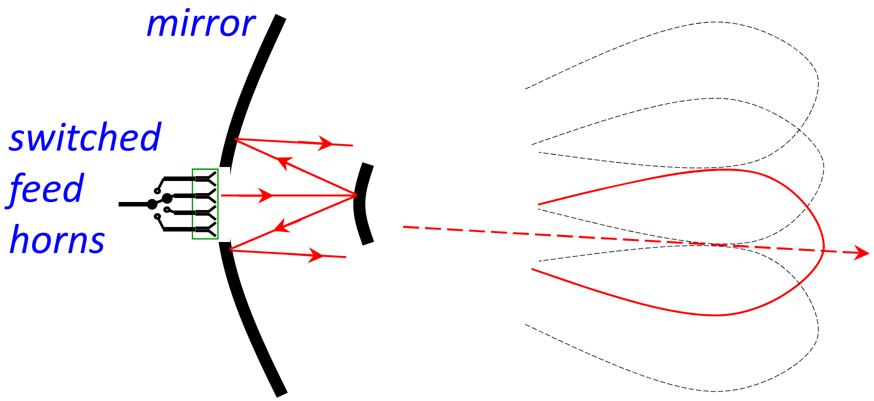
… cost driver due to required manpower

→ dishes with switched focal plane array for small-angle electronic beam alignment

→ based on inexpensive feed-horn array and numbers of switches

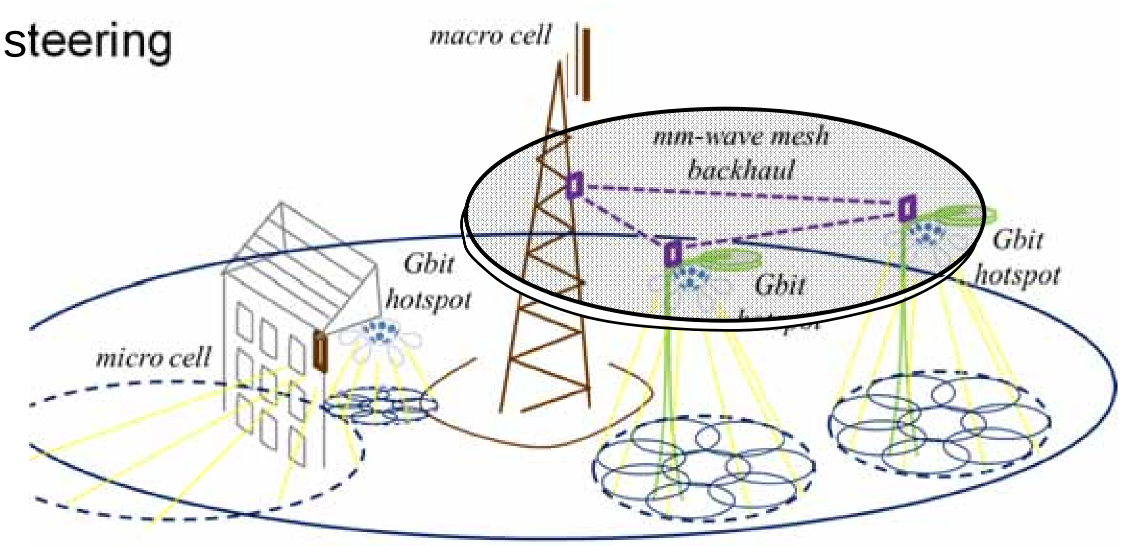
… feasible but cost is an issue



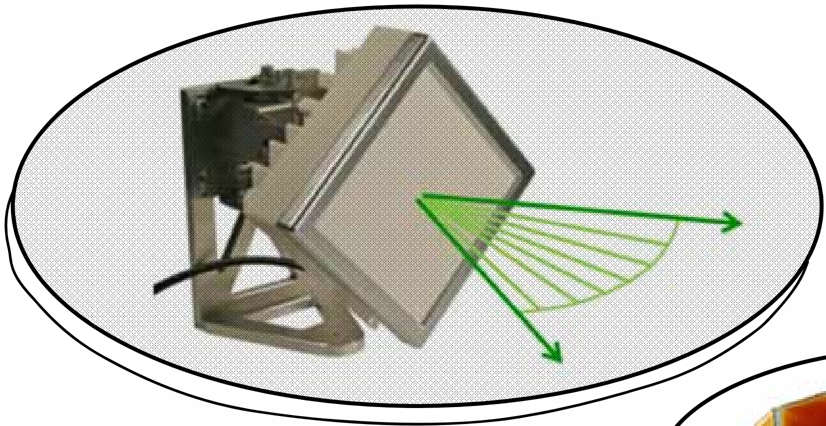
# wide-angle azimuth beam steering for mm-waves:

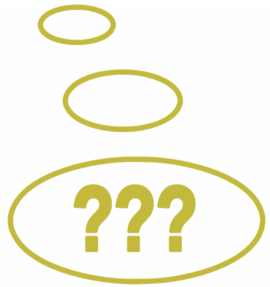
mm-wave wide-angle beam steering
is an enabler for
GBps wireless
adaptive mesh backhaul

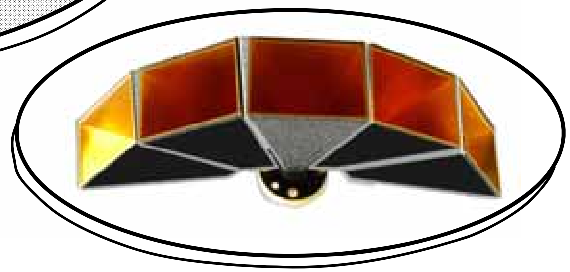



<u>phased arrays</u>:
- feeding each array element with a separate transceiver is too expensive.

<u>beam forming networks</u>:
- are very lossy for high frequencies and/or for reasonably large number of beams





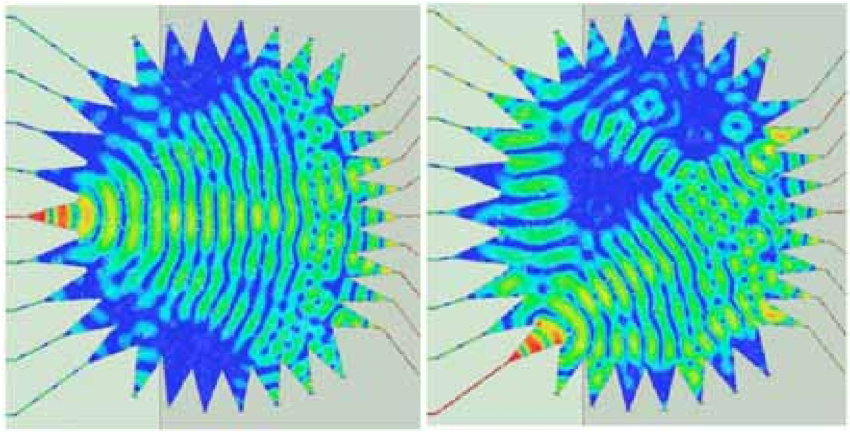
… examples

# wide-angle azimuth beam steering for mm-waves:

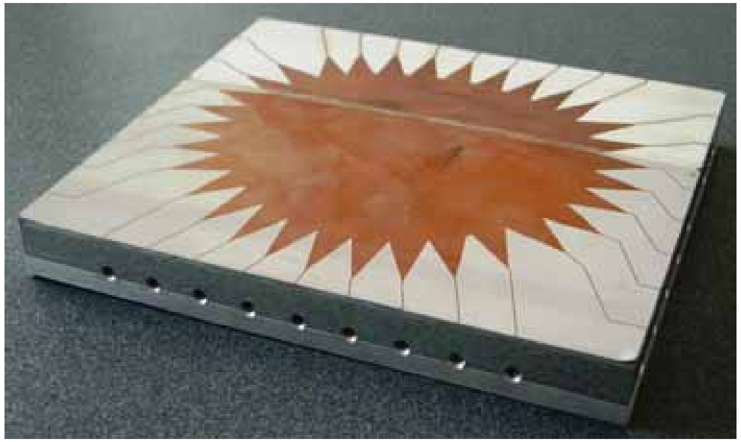
beam forming networks:

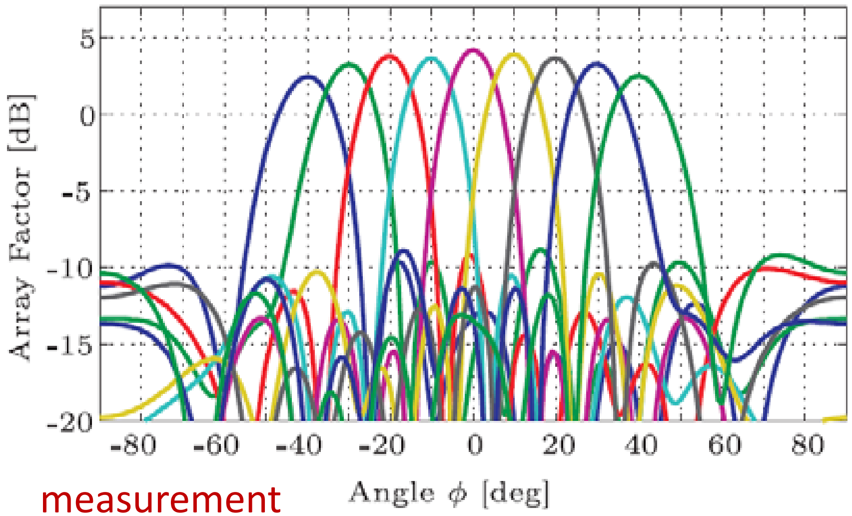
- example 1:
  10 GHz Rotman lens (9:9)
  avg. 50% dissipative loss
  10% @ dummy ports

split-dielectric Rotman lens [G. Tudosie, 2009] :



simulation



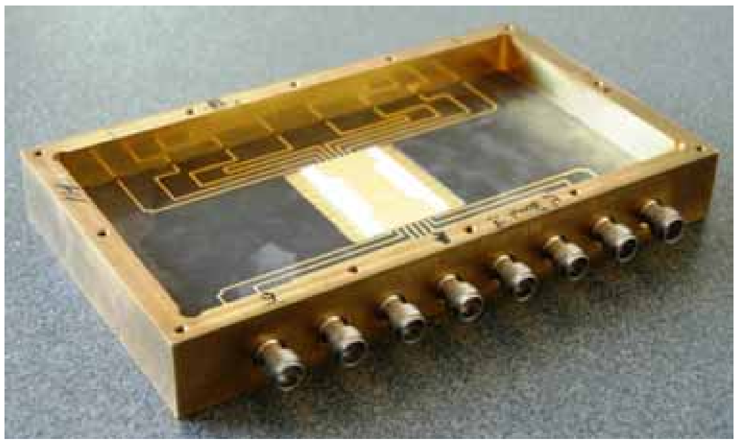



measurement

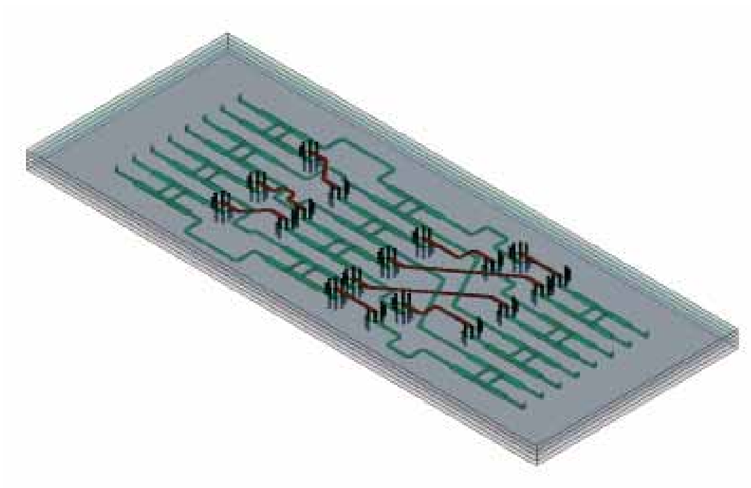
# wide-angle azimuth beam steering for mm-waves:

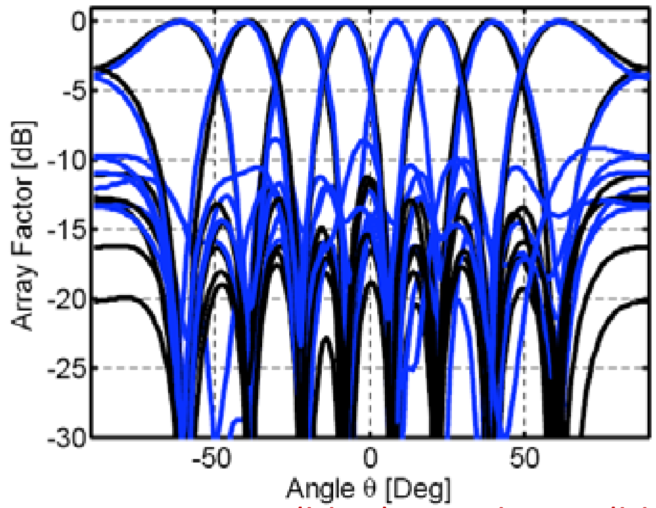
beam forming networks:

- example 2:
  60 GHz Butler matrix (8:8)
  5 layer LTCC (Ferro AS6-S, 0.2mm)
  avg. 80…85% dissipative loss
  in the LTCC Butler matrix
  (and another 80…85%
  loss in the feed circuitry)



LTCC Butler matrix [G. Tudosie, 2009] :





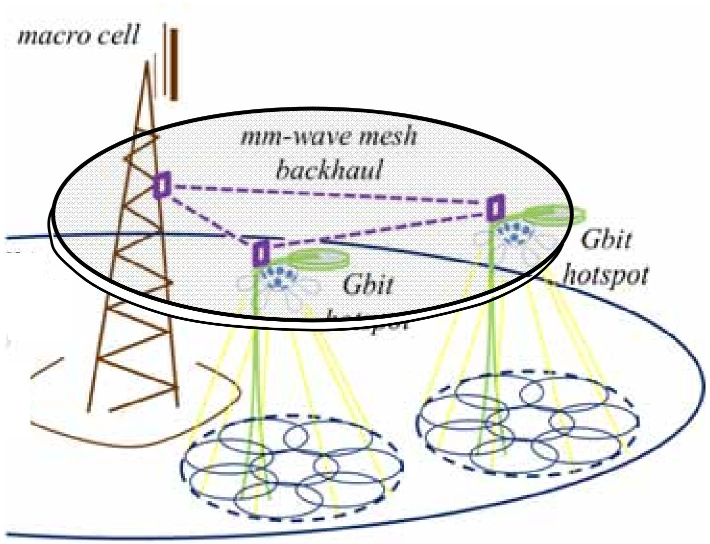

AF measurement (blue), simulation (black)

# wide-angle azimuth beam steering for mm-waves:

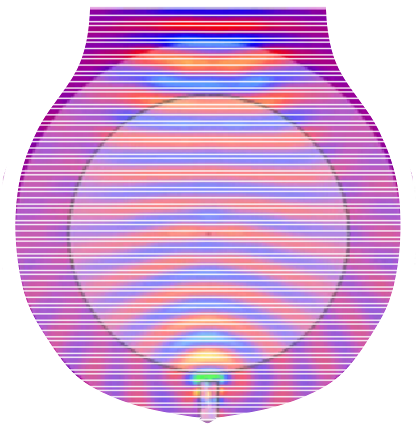
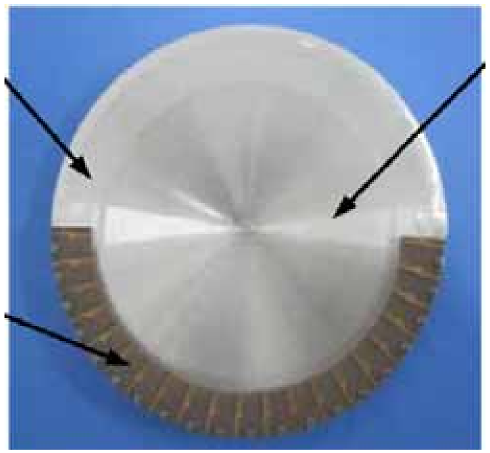
phased arrays, Rotman, Butler do not work
- too expensive, too lossy

requirement for high efficiency results in
- optical space feed beam forming or
- multiple-feed parabolic mirrors or lenses

primary need for wide-angle steering in azimuth will simplify the problem (1D mirror or lens)



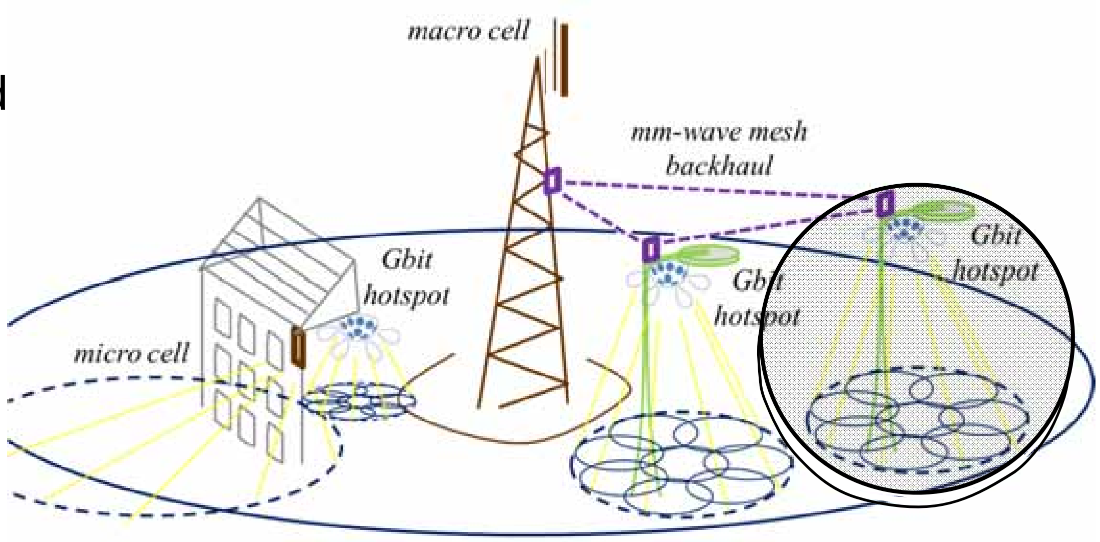

→ 30 GHz planar TE mode air/metal Luneburg lens :

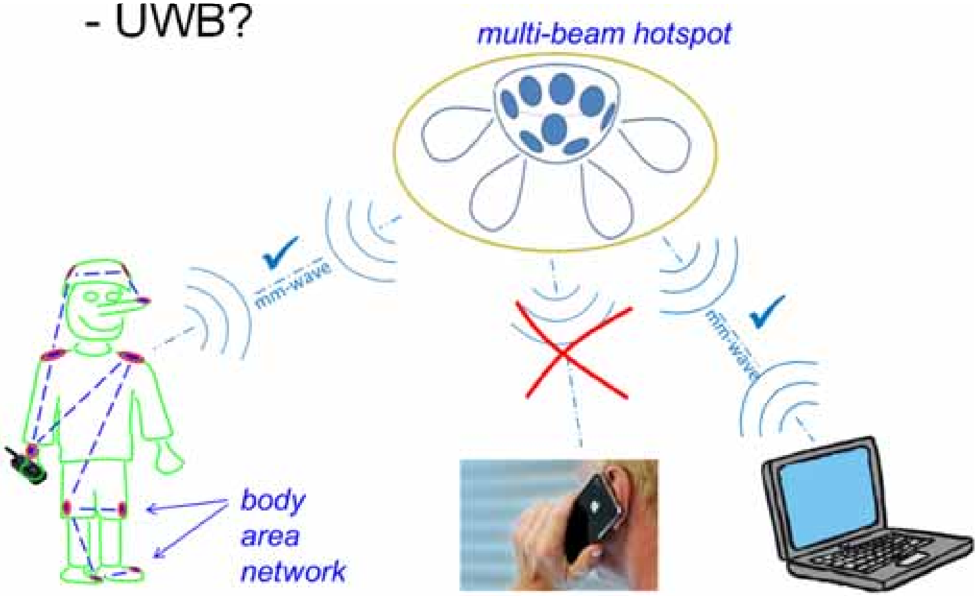

[ C. Hua *et al*., IEEE Trans. MTT, vol. 61, no. 1, January 2013, pp. 436-443 ]

## wide-angle θ & φ beam switching for mm-waves:

GBps at the wireless UE requires short range, directed mm-wave beams




LOS likely to be very helpful.
On the UE-side:
→ GBps on-body multi-hop network needed
- mm-wave?
- UWB?



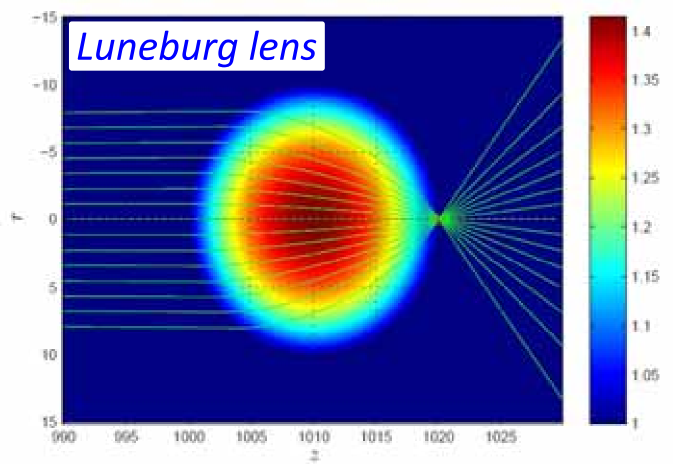
# wide-angle θ & φ beam switching for mm-waves:

mm-wave multi-beam hotspot

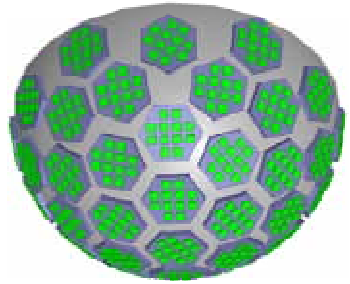
- with hemispherical coverage,
- with switched-beam pattern,

e.g., 1‘000 beams of 32 dBi :

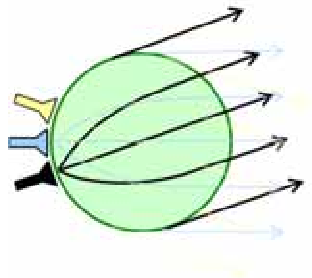
- on the surface:
  $\varnothing_{sphere} \approx \underline{280\ \lambda}$
- using a graded lens:
  $\varnothing_{sphere} \approx \underline{14\ \lambda}$



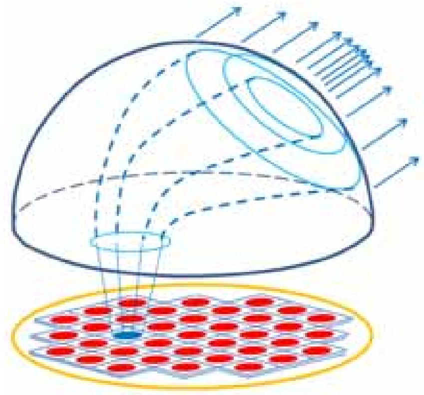

multitude of patch arrays on a hemi-spherical surface



principle of Luneburg lens



modified Luneburg lens allowing planar feed array



# conclusion:

- adaptive antennas will find various applications on the infrastructure side of wireless networks

- only quite specific forms and features of antenna adaptivity makes sense from a point of view of performance, form factor, cost

- system design needs to take into account adaptive antennas at a very early stage