Adaptive Antennas for Wireless Communications

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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 $\theta$ & $\phi$ beam steering
  . wide-angle azimuth beam steering
  . wide-angle $\theta$ & $\phi$ 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

- more frequency bandwidth
  - ... can millimeter-wave be an option? (LOS!)
  - ... or infrared?
  - ... but: not much left „unused“ between 0.7 and 2.8 GHz
- more clever coding
  - ... cognitive radio (frequency sharing) is „promising“
  - ... but: today’s algorithms are close to Shannon’s limit
- less power per user
  - ... lower power, i.e., shorter range, i.e., small cells & het nets

→ adaptive antennas come into play here
wireless mobile versus nomadic

not all cellular traffic is „mobile“:

- 50% of all traffic generated in 1 cell¹.
- 80% data traffic carried by 3 cells¹.
- Remaining 20% carried over 28 cells.

† 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

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different needs for antenna adaptivity

- wide-angle azimuth beam steering
- frequency-selective elevation beam steering
- broadbanding / frequency adaptivity
- small-angle $\theta$ & $\varphi$ beam steering
- wide-angle azimuth beam steering
- wide-angle $\theta$ & $\varphi$ beam switching

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

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

*low freq backhaul? probably not*  *mm-wave cellular? probably yes*

- backhaul?
- probably not
- probably yes

[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
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
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
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 $\lambda/2$ 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 $\theta$ & $\varphi$ 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

phased arrays:
  feeding each array element with a separate transceiver is too expensive.

beam forming networks:
  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 $\theta$ & $\phi$ 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 $\theta$ & $\phi$ beam switching for mm-waves:

mm-wave multi-beam hotspot
- with hemispherical coverage,
- with switched-beam pattern,

\[ \text{e.g., 1'000 beams of 32 dBi :} \]
- on the surface:
  \[ \varnothing_{\text{sphere}} \approx 280 \lambda \]
- using a graded lens:
  \[ \varnothing_{\text{sphere}} \approx 14 \lambda \]
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