Antennas for MIMO systems

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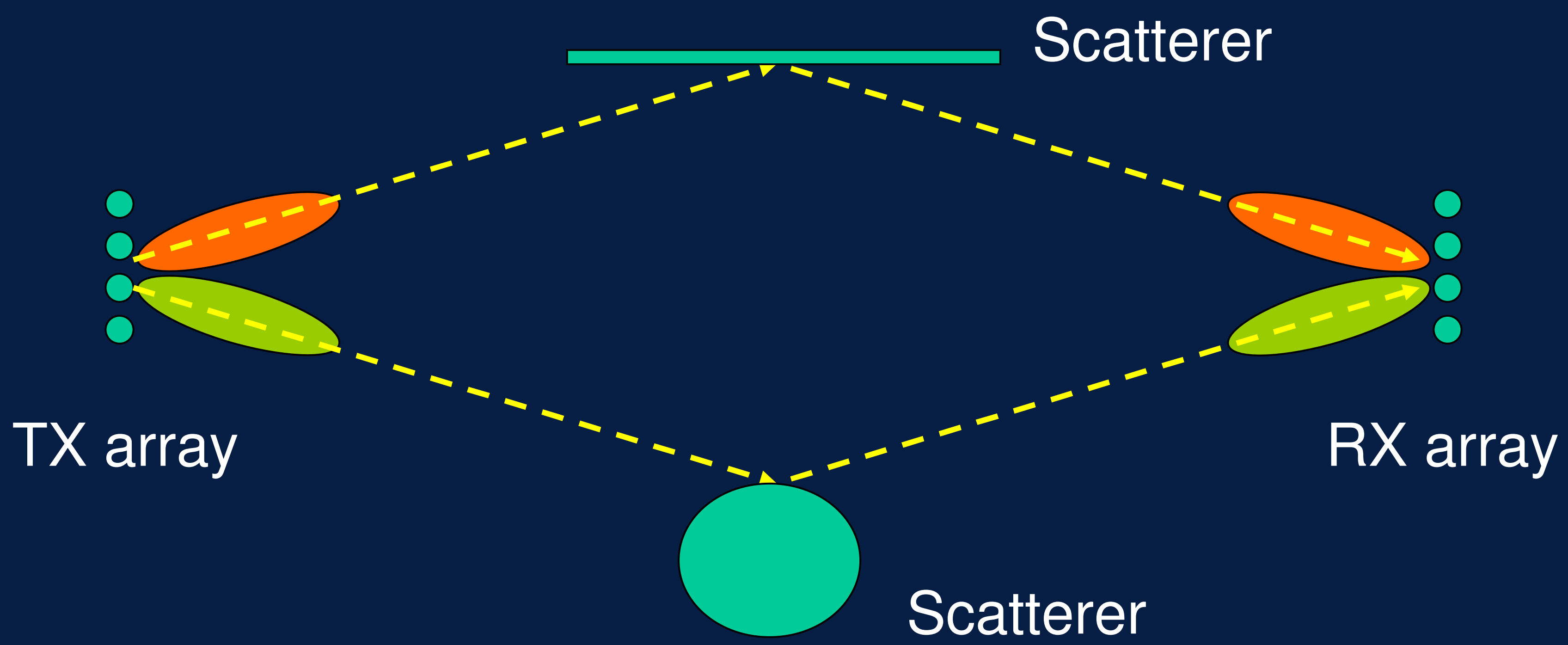
Introduction

This presentation examines the requirements for a MIMO antenna configuration for a user equipment (UE). It reviews:

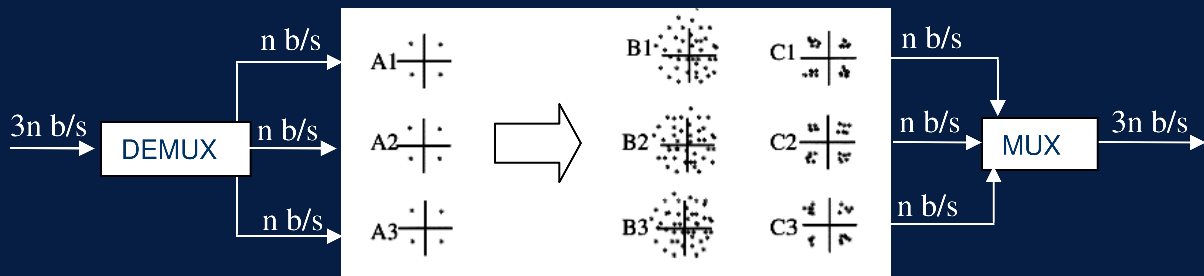
- The spatial multipath concept of the MIMO channel
- Performance in the real world: the trade-off between channel reliability and enhanced data throughput
- Requirements for antennas
- Results in a CDMA cellular environment
- Network priorities for implementation

MIMO in a simple environment



- Both arrays must be capable of resolving the two paths
- If the paths carry different data streams, increased throughput is achieved without increased bandwidth

Signal constellations



Symbol constellations from a 3 x 3 example

A1,2,3 as transmitted by three TX antennas

B1,2,3 as received by three RX antennas

C1,2,3 after processing, at the inputs to three demodulators.

The three parallel symbol streams were derived from a single stream at 3 times the symbol rate, and are subsequently reassembled in the original time sequence

Constraints of the channel

- Since the transmit vector is projected onto the channel matrix **H**(ω), the number of independent data streams that can be supported is limited by the rank of **H**(ω)
- The properties of **H**(ω) determine the potential performance for a MIMO system

The channel matrix

The channel matrix **H**(ω) comprises the effects of:

- Array size
- Antenna configuration
- Element pattern
- Element polarisation
- Element coupling
- Antenna impedance matching
- Multipath propagation characteristics

All of these are characteristics of the transmit and receive antennas

- no multipath, no MIMO

MIMO v Diversity

- For simple point-to-point transmission (SISO), multipath propagation creates fading and signal loss
- We can restore this degradation using diversity techniques, but the channel is no better than an unobstructed single path
- MIMO offers an enhanced data rate with no increase in bandwidth

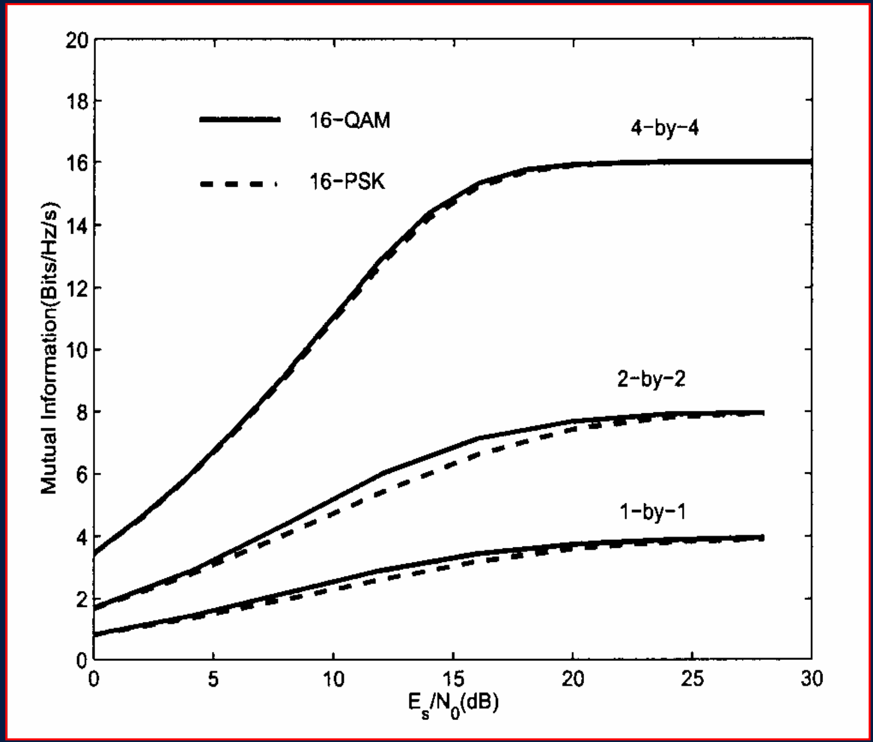
Knowledge of the channel

- In a mobile environment we have no *a priori* knowledge of the channel
- By the time we have sounded m x n channels, everything will have changed and we will have no useful result
- In a "portable" application the rate of change could allow effective channel sounding

The prize

- **In a rich multipath environment** a MIMO system with M transmitting and M receiving antennas provides M^2 transmission channels and has a potential throughput up to M times that of a single channel occupying the same bandwidth
- **Every property** of a MIMO system depends on the statistical properties of the environment

MIMO spectral efficiency



Spectral efficiency (b/s/Hz) for different Eb/No, antenna numbers and modulation formats

Source: Ref 2

Diversity and spatial multiplexing

- In traditional antenna diversity, spatial re-sources provide duplicate copies of a single information stream in order to increase the reliability of detection

- In spatial multiplexing, different information streams are sent over separate spatial channels to increase throughput and spectral efficiency

- MIMO can achieve a mixture of these benefits, trading them against each other, according to the environment and the QoS requirements

Trade-off

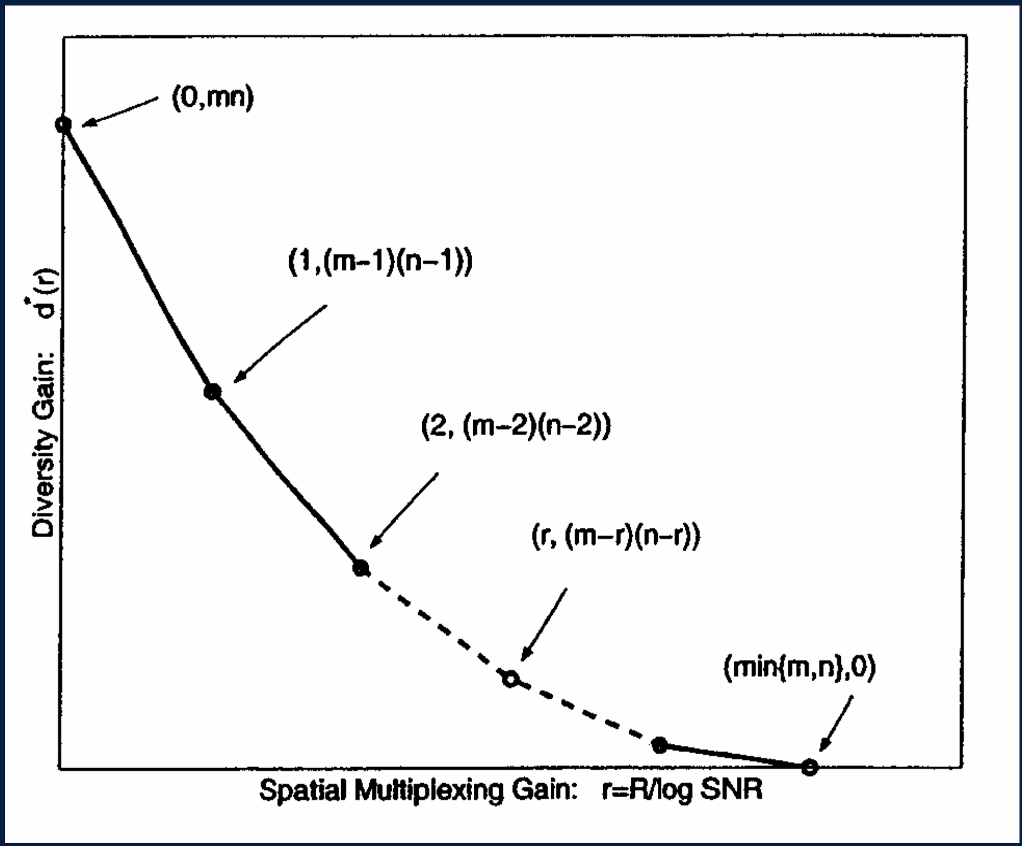
MIMO systems provide a trade-off between diversity gain and spatial multiplexing gain. When either is being fully exploited, the other falls to zero.

In severe fading conditions all available resources are used to maintain the channel.

As things improve the resources allow the channel capacity to be increased.

System with m x n antennas

Source: Ref 3 © IEEE



Increasing order of multipath

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- The complex maths of a MIMO system makes it difficult to understand intuitively the impact of individual antenna parameters
- A MIMO system operates in different signal regimes, and must be capable of making the best use of the signals available in any of them
- Antenna system design and processing algorithms must take account of this

Low correlation

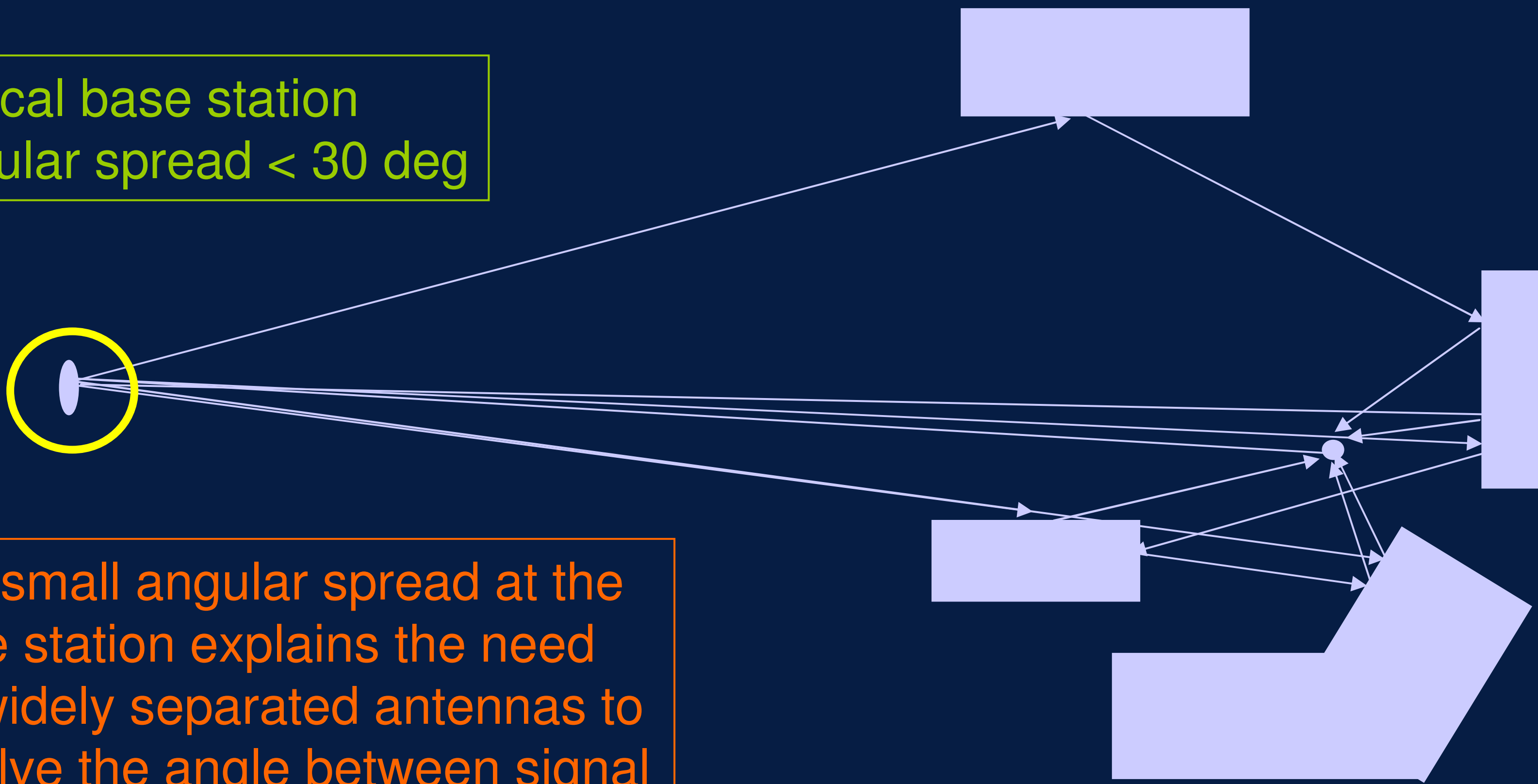
- Low correlation between antenna outputs is a necessary but not sufficient condition for good MIMO performance
- Low correlation is achieved when each antenna provides a unique weight to each individual multipath component
- This weight can be due to antenna location (spatial diversity), antenna pattern (angle diversity) or polarisation (polarisation diversity) or all of these

…unfortunately…

- Low correlation generally occurs for a large set of multipath components with large angular spread. (good)
- The rich scattering required to achieve this generally also produces low SNR, which in turn decreases channel capacity (bad)
- But some investigators report that good improvements in channel capacity can be realised with correlations as high as 0.5

Angular spread regime in mobile radio

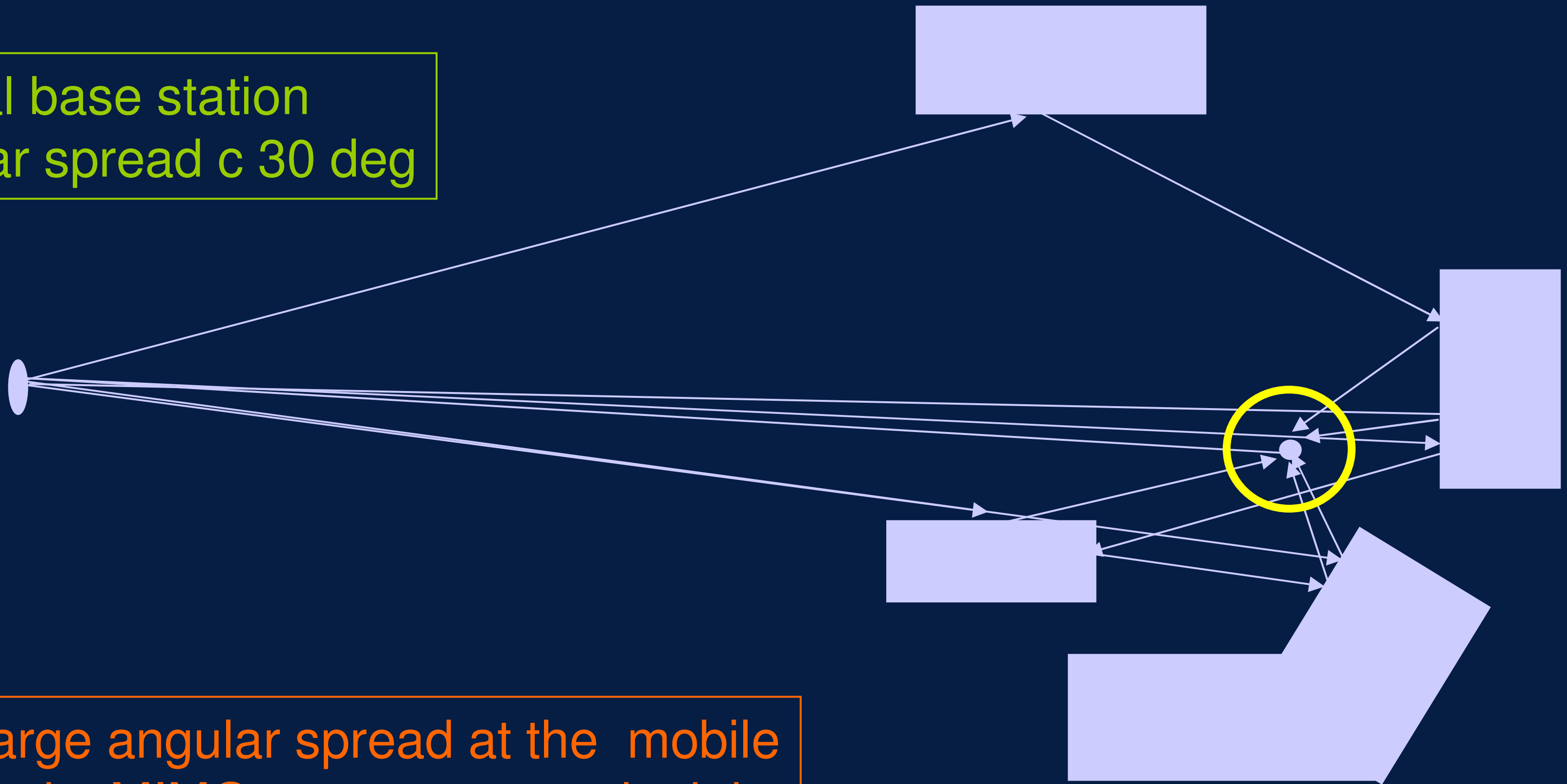
Typical base station
Angular spread < 30 deg



The small angular spread at the base station explains the need for widely separated antennas to resolve the angle between signal paths and get effective space diversity

Angular spread regimes

Typical base station
Angular spread c 30 deg



The large angular spread at the mobile means its MIMO antennas must look in all directions to find usable signal components.

Typical mobile
Angular spread 360 deg

Radiation patterns

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At both ends of a link –

- The antennas must be sufficiently spaced to allow resolution of the multipath components
- Taken together, the antenna patterns must cover the whole solid angle over which signal components are likely to arrive

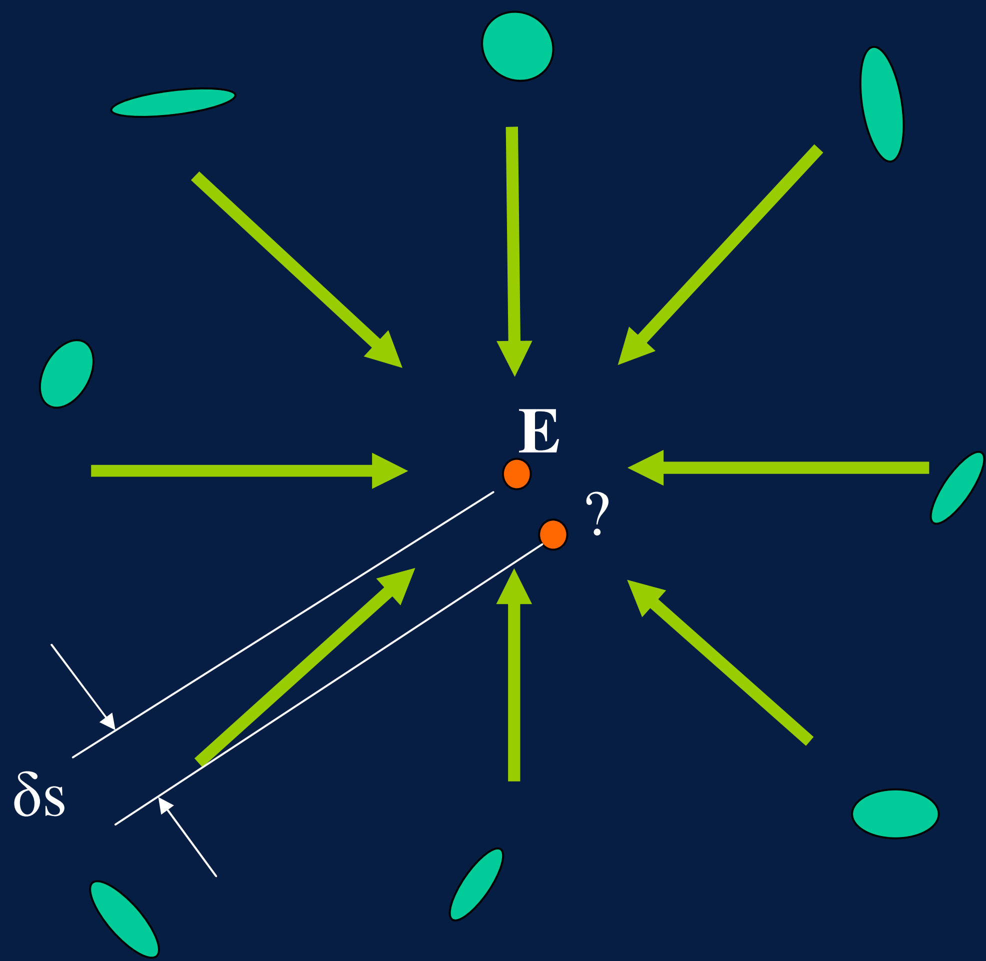
This implies widely spaced antennas at the base station, but allows relatively closely spaced antennas at the UE.

Switched beams v switched antennas

- There are two methods for producing patterns covering different regions of space:
    - Switching between individual directional antennas
    - Switching between multiple beams formed from a single multi-element array

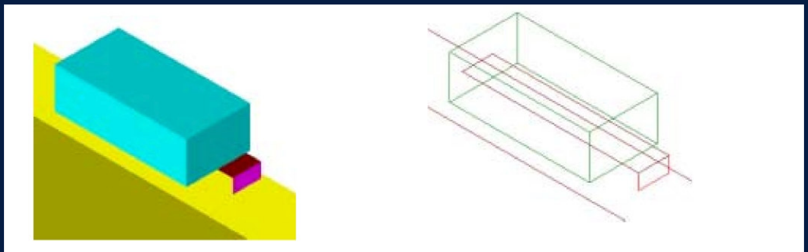
In both cases the constraints of an electrically small platform limit the capabilities that can be realised.

Correlation v spacing

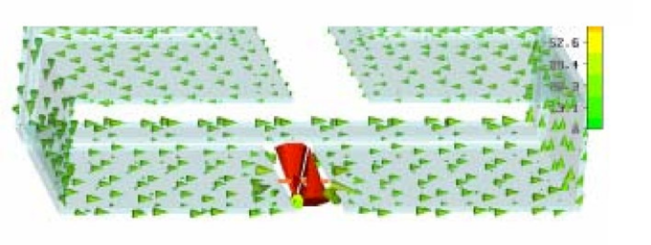


With rich multipath the correlation between signals from even closely spaced antennas is very small, but for very small spacings the outputs of two antennas will be influenced by mutual coupling.

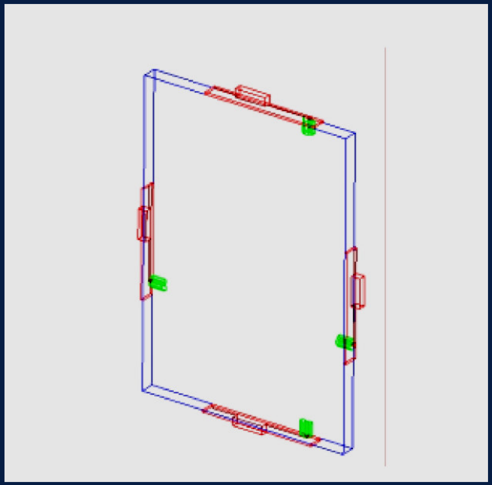
Realisation



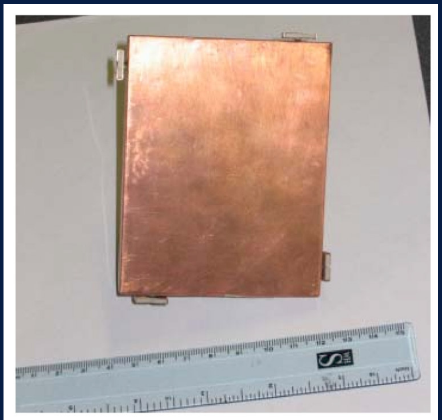
Dielectric antenna technology creates small efficient antennas covering one or more frequency bands. Their contained near-field minimises inter-antenna coupling



Folded loops demonstrated the advantages of balanced antennas



The performance of a group of antennas on a PDA is simulated to optimise positioning



The antennas are mounted on a mock-up user device, ready for pattern and isolation measurements

Results

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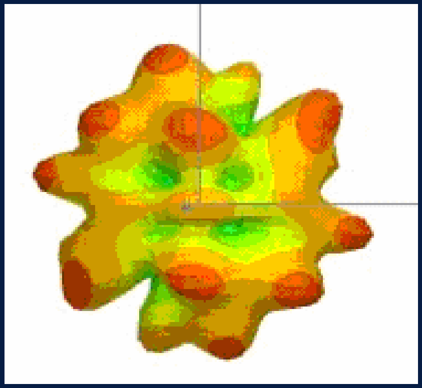
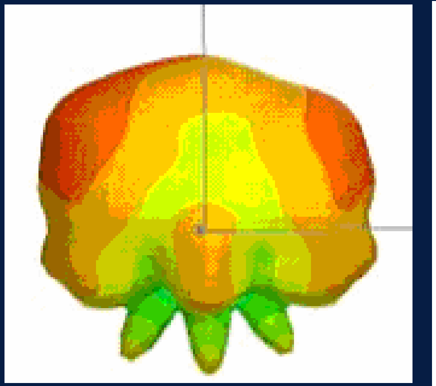
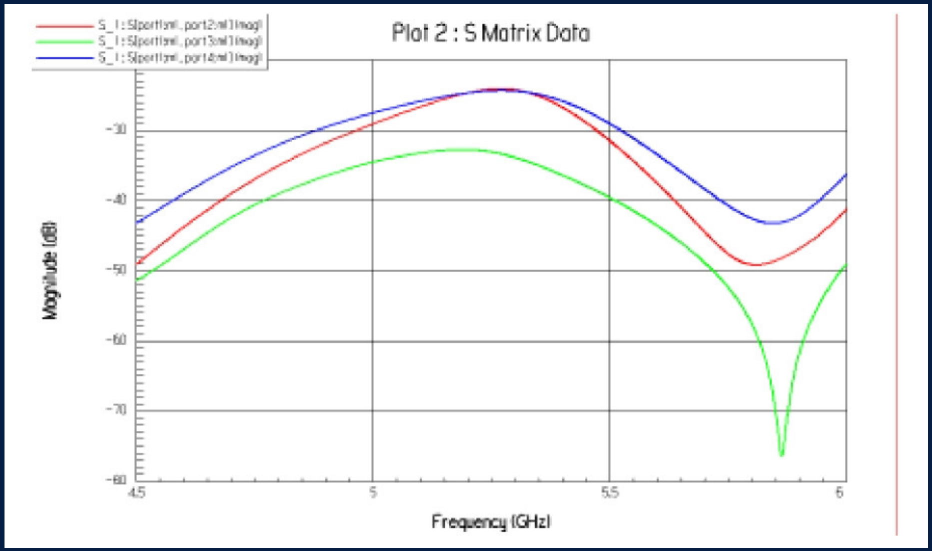






Measured results show it is possible to achieve functionally useful pattern de-correlation and isolation even on a small groundplane in a hand-held device, but most of the de-correlation relates to signal phase, not pattern shape.

	Magnitude of spatial correlation coefficient			
Element	**1**	**2**	**3**	**4**
1	1	0.0495	0.0087	0.0221
2	0.0495	1	0.0189	0.008
3	0.0087	0.0189	1	0.0385
4	0.0221	0.008	0.0385	1

An ideal mobile MIMO receiving antenna ensemble….

- forms several concurrent overlapping beams in any azimuth direction (or any direction in 3D space)
- responds to signals with any polarisation
- provides isolation between outputs
- provides outputs with low cross-correlation
- has high efficiency

These objectives are not mutually incompatible, but are not easy to achieve on a small platform.

Base station antenna choice

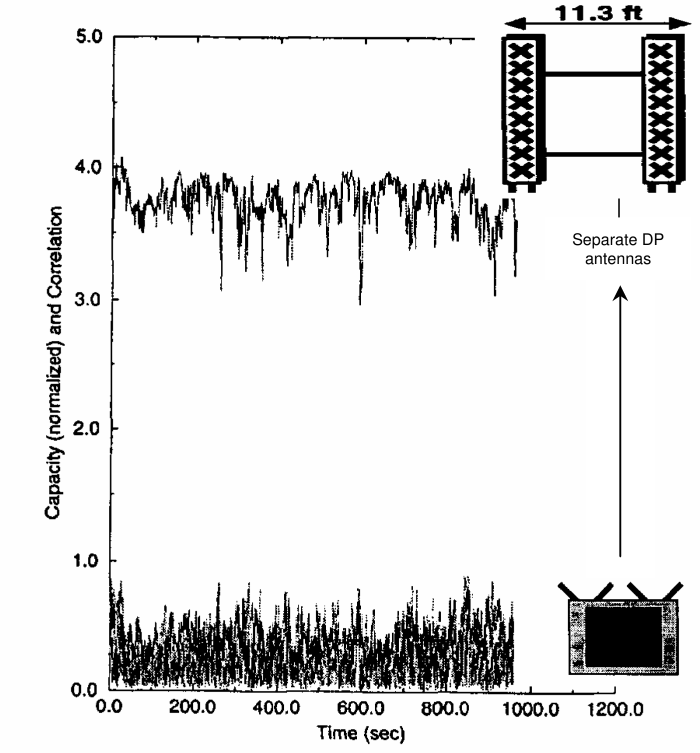


Fig. 3. Measured normalized capacity and correlation versus time for case 4.

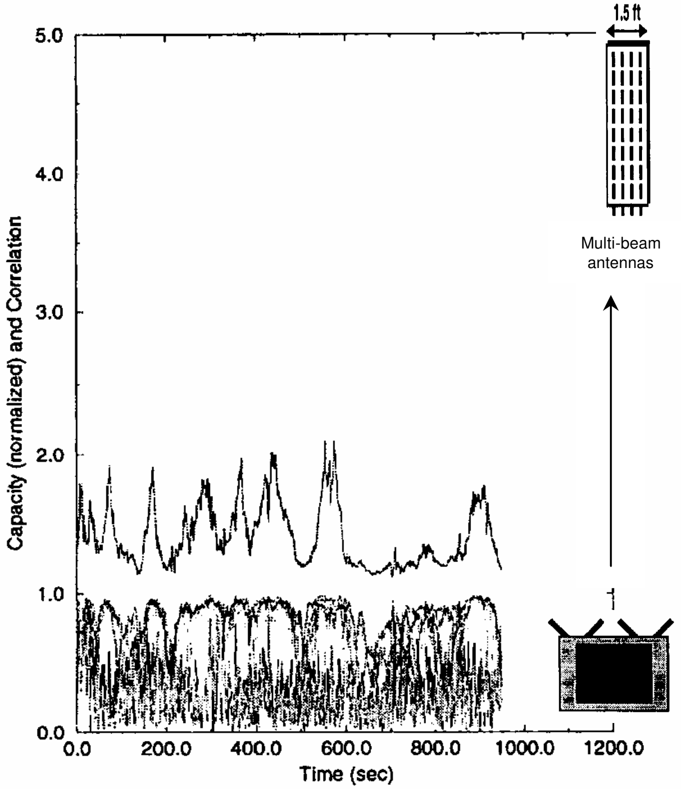
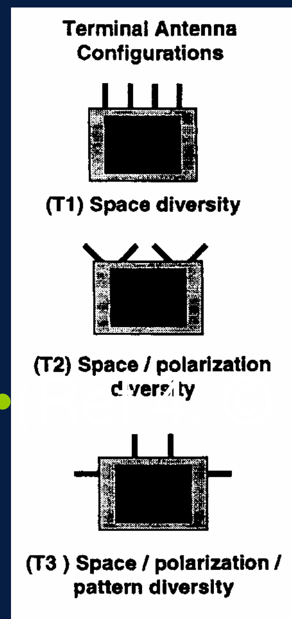


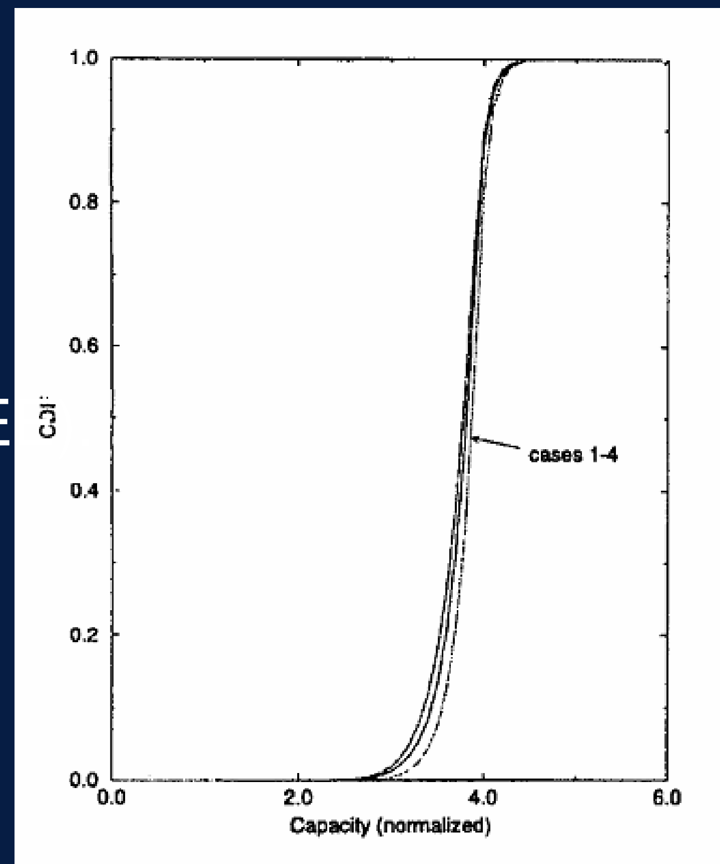
Fig. 5. Measured normalized capacity and correlation versus time for case 6.

Practical measurement of the increase in capacity relative to a single antenna, using different antenna combinations. Residential area with trees, 1900MHz, CDMA, ~2 mile range, 30mph. (Ref 4, © IEEE).

UE antenna choice

Surprisingly, the choice of antennas for the user equipment appears to have little effect on system performance (Laptop platform)





Cumulative probability functions for systems with various antennas at the UE (Ref 4, © IEEE).

Cases 1 – 4 use the three monopole configurations shown, plus 4 standard handset antennas; the BS antennas were the dual XP arrays.

State of the market

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- MIMO is already available in WiFi / WiMax
- MIMO is being considered by 3GPP for use in later releases of the UTRAN standard
  - Adoption will depend on cost/benefit analyses
  - Problems with external antenna sizes
  - Handset constraints
  - Not before 3 – 5 years out
  - MIMO is regarded as a 4G technology
    - Tx diversity, 4-branch RX diversity and handset diversity are likely to be implemented first (+ SAIC for GSM)
- MIMO / OFDM is currently the favoured combination

Conclusion

- MIMO is here to stay
- It is being applied to LANs and MANs NOW – not certain whether it will be applied to existing 2G or 3G systems
- Antennas for UEs will always be constrained by basic practical issues, but the potential for success is there

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