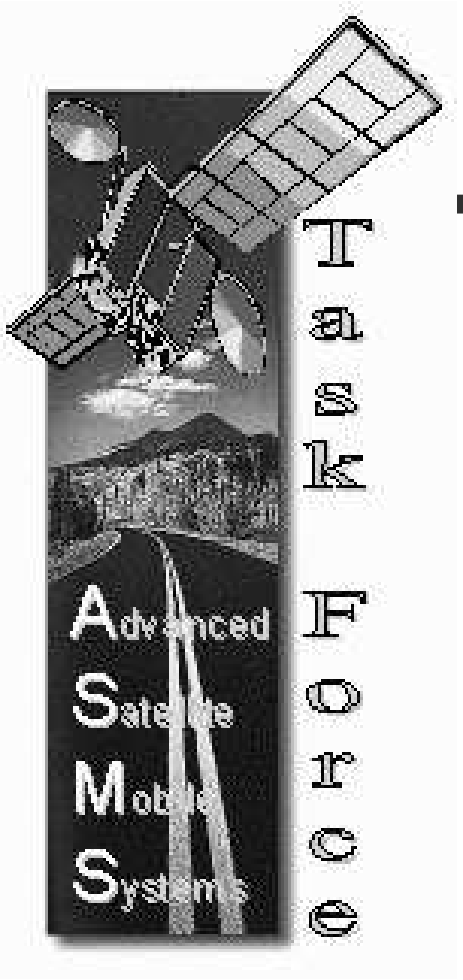

EMPS/ASMS2004

MAESTRO

Satellite Downlink Reception through Intermediate Module Repeaters:

Power Delay Profile Analysis

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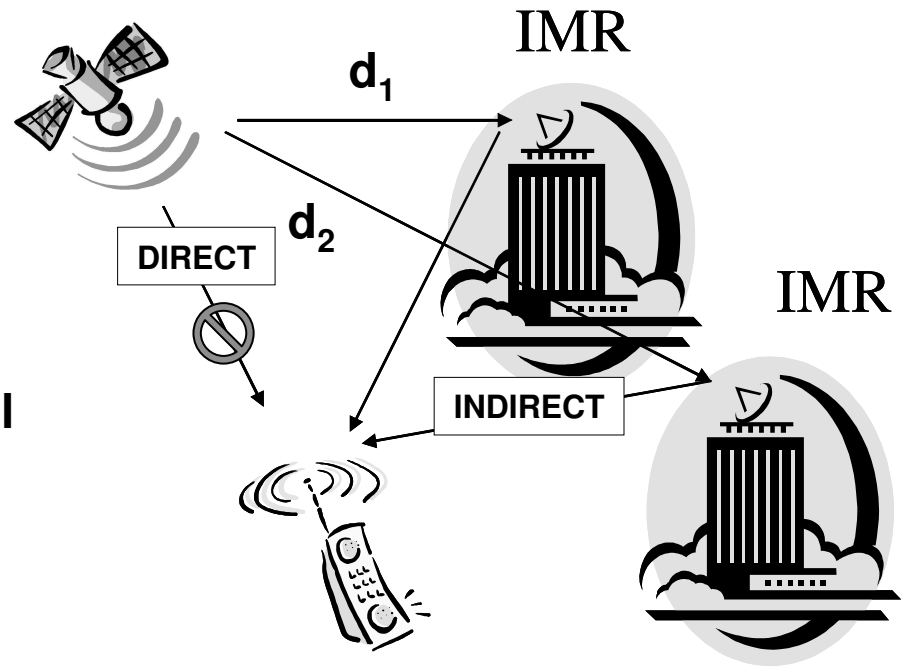
Messages

- Universal frequency reuse is (almost) unavoidable for IMRs
- IMRs: extending coverage while expanding delay spread in 4 ways
- Multipath propagation channel: many degrees of freedom
- Spread spectrum transmission: resilience through raking proportional to spreading factor
- Impact on receiver design: diversity is not always beneficial (coverage is not the entire picture)

IMRs, gap fillers, terrestrial repeaters...

- Many satellite systems foresee an ancillary terrestrial component to cover densely built-up areas and indoor environments
- The repeaters provide boosted replicas of the signal
- Unless IMRs are intelligent, universal frequency reuse is a must!
- However, IMRs are not fed synchronously by the satellite
- Hence, large differential delays



Delay Analysis: 4 ways to increase dispersion

- **Delay components:**
  - **Sat-IMR: Satellite differential delays due to different distances between the satellite and the IMRs**
    - **satellite elevation angle, IMR deployment**
  - **IMR-UE: Terrestrial differential delays due to different distances between the user equipment and the IMRs**
    - **UE location**
  - **IMR-UE: Multipath on each terrestrial link (IMRs typically on rooftops)**
    - **delay spread of the channel power delay profile (PDP)**
  - **Sat-UE/IMR-UE: differential delay between the signal received directly from the satellite and that received by the reference IMR**
    - **dependent on both the user equipment location and the satellite elevation angle**
- **...and this holds for a GEO satellite!**

Degrees of freedom

- Single IMR PDP: the channel for each IMR is a terrestrial multipath propagation channel, with a delay spread of a few μs
- Composite PDP: the 4 delay components produce an even more dispersive PDP, with a large overall delay spread
- Degrees of freedom (DoF) = number of resolvable paths in the composite PDP
- Frequency-flat channel: DoF = 1, Selective channel: DoF > 1
- Rule of thumb:

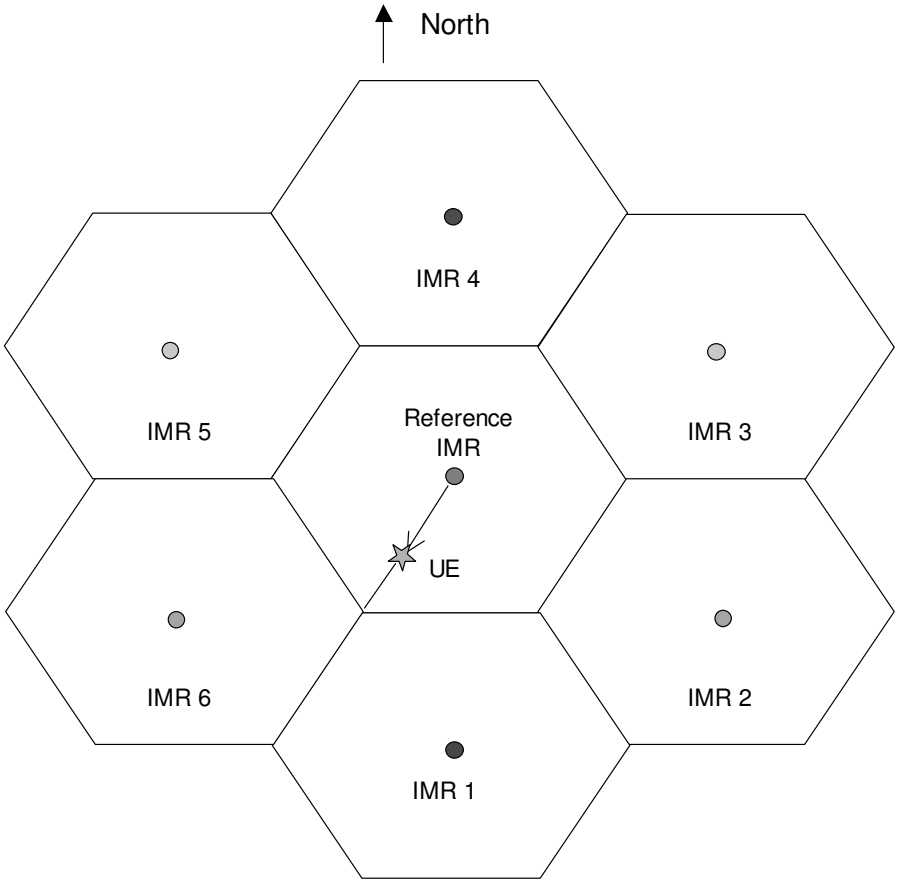
  DoF = delay_spread x chip_rate = signal_BW/coherence_BW

- For example: chip_rate = 3.84 Mcps, delay_spread = 1 μs, DoF = 3.84 ~ 4
- The IMR channel provides many degrees of freedom!
- Not all DoFs are active simultaneously: specific composite PDPs

Low Power and High Powers IMRs

- **Low Power IMRs: simple repeaters**
  - **The signal received from the satellite is simply retransmitted in the same frequency band, without any processing but an analog amplification.**
  - **As the use of the same frequency sets strict constraints on the maximum Tx power they are identified as low power IMRs**
  - **We assume a coverage radius of about 400m**
- **High Power IMRs: frequency conversion repeaters**
  - **Two different frequencies are used for transmitting and receiving**
  - **Previous power limitations do not apply: they are consequently identified as high power IMRs.**
  - **We assume a coverage radius of about 2 km**

IMR cellular layout: geometrical modeling



- Every IMR transmits with the same fixed power
- Hexagonal cells are assumed (not essential)
- The UE is inside the “reference” IMR cell
- The first tier of six neighbouring IMRs is considered
- The UE is moved along a straight line from the proximity of the cell centre (a tenth of the cell radius) to a corner (a cell radius)

Propagation Models

- **Satellite propagation**
  - **satellite-to-IMR: free space propagation**
  - **satellite to UE: free space propagation, non-selective Rice fading superimposed (DoF = 1)**
- **Terrestrial propagation: IMR-to-UE links**
  - **described by the ETSI model [4], including average attenuation, shadowing and multipath fading. Delay spread: around 10 Tc**

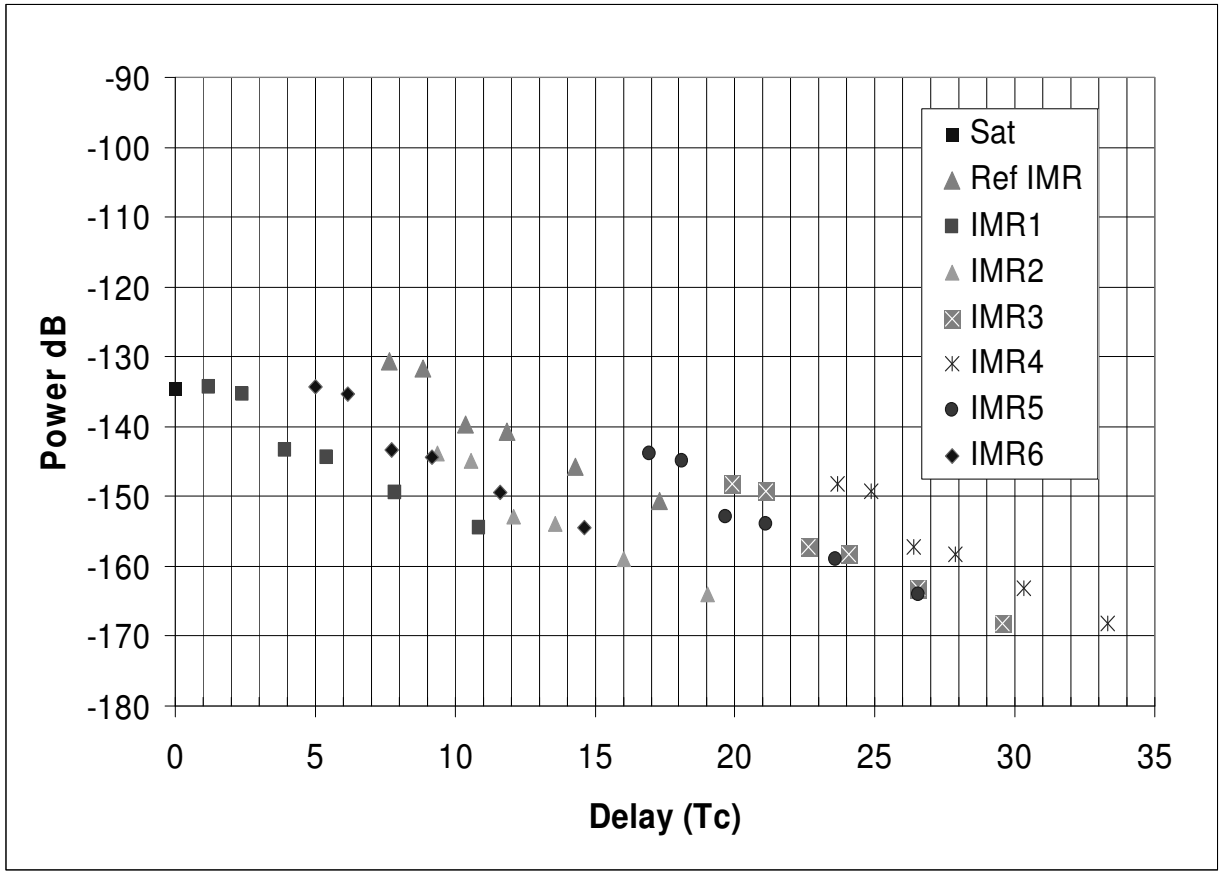
ETSI Vehicular High Antenna Channel A		
Tap	Intensity (dB)	Delay (s)
1	0	0.00E+00
2	-1	3.10E-07
3	-9	7.10E-07
4	-10	1.09E-06
5	-15	1.73E-06
6	-20	2.51E-06

Significant paths: Link budget

Sat-to-UE link (direct component)		IMR-to-UE link (indirect components)	Low Power	High Power
EIRP/Traffic code (dBW)	57	EIRP/Traffic code (dBW)	-19	10
Path Gain (dB) (free space)	-192.5	Path Gain (dB) (ETSI, d=0.86)	-112.8	-139.2
Polarization Gain (dB)	-1	Polarization Gain (dB)	-1	-1
UE Antenna gain (dB)	2	UE Antenna gain (dB)	2	2
Received Power (dBW)	-134.5	Received Power (dBW)	-130.8	-128.2

Power delay profile

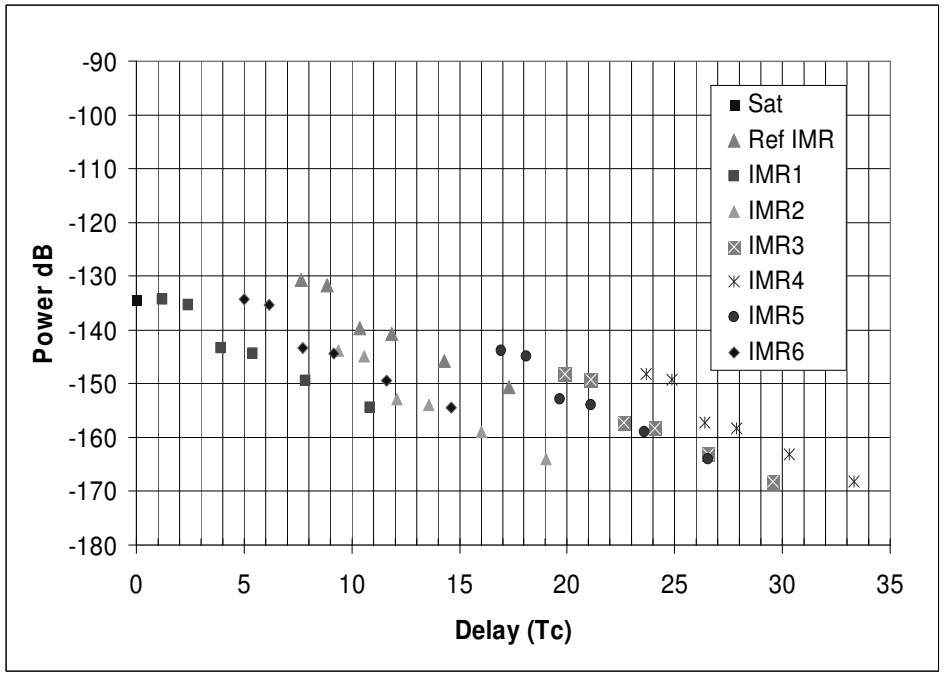
Low Power IMR (Lat. 51 North, *d* = 0.86; reference case)



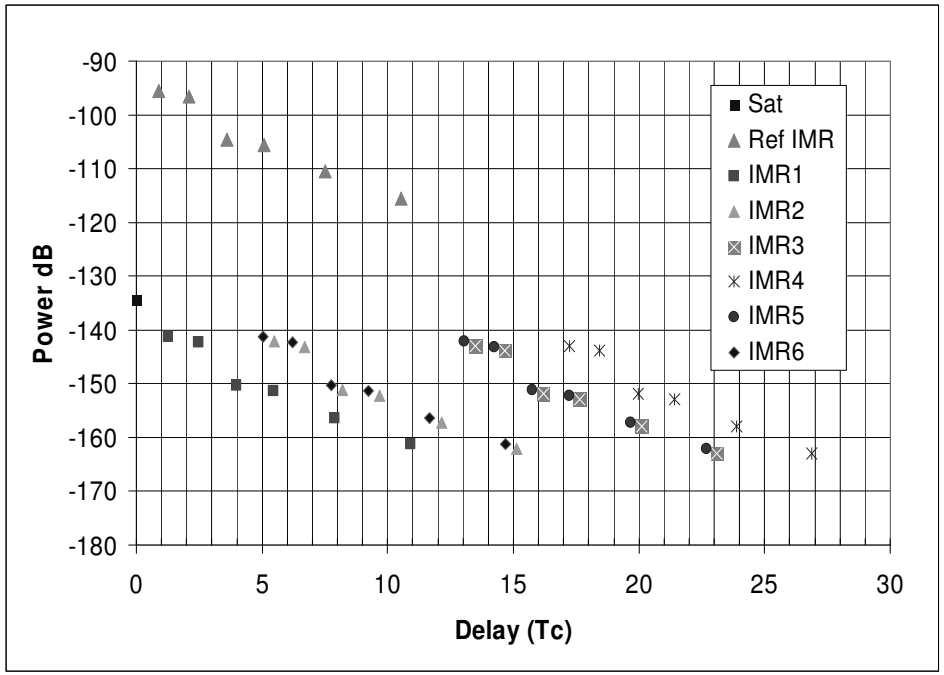
- chip rate=3.84 Mchip/s
- UE-to-IMR distance, *d*, normalized to the cell radius
- 43 signals components:
  - 1 direct
  - 6 (taps) x 7 (IMRs)
- Delay spread largely increased by Multi IMR reception

Power delay profile
variation as a function of UE distance from reference IMR

- Low Power IMR (Lat. 51 North, *d* = 0.86)



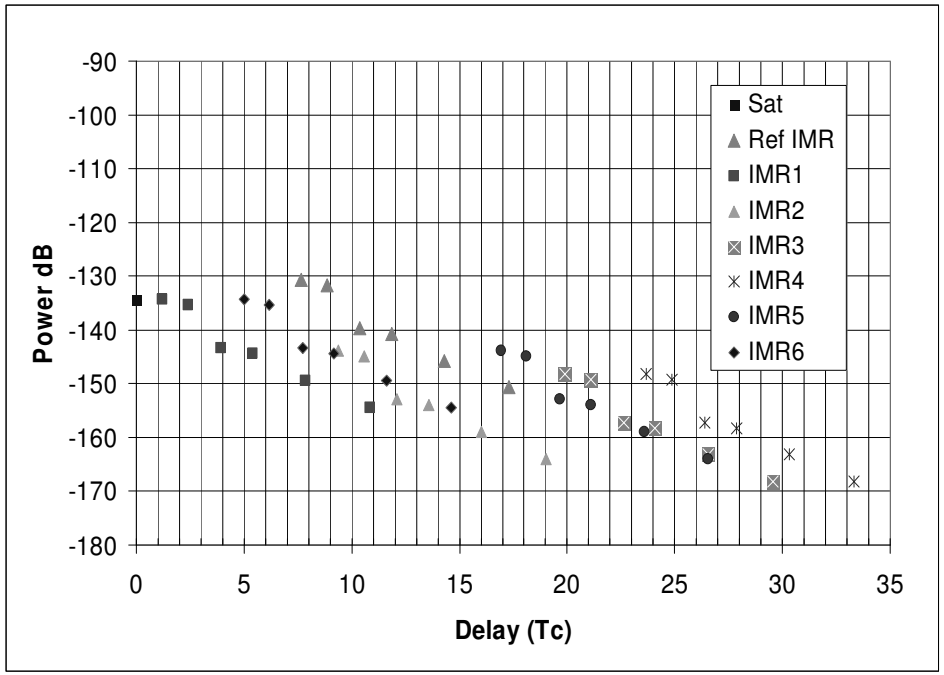
- Low Power IMR (Lat. 51 North, *d* = 0.1)



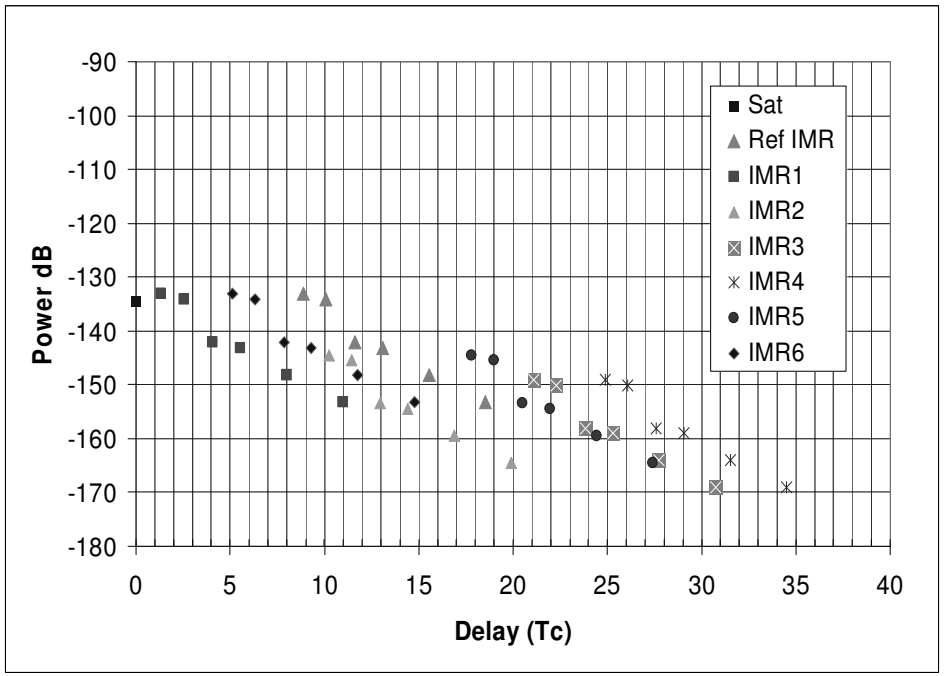
- At a short distance from the reference IMR the contributions of direct satellite component and of other IMRs are negligible

Power delay profile
variation as a function of UE distance from reference IMR

- Low Power IMR (Lat. 51 North, *d* = 0.86)



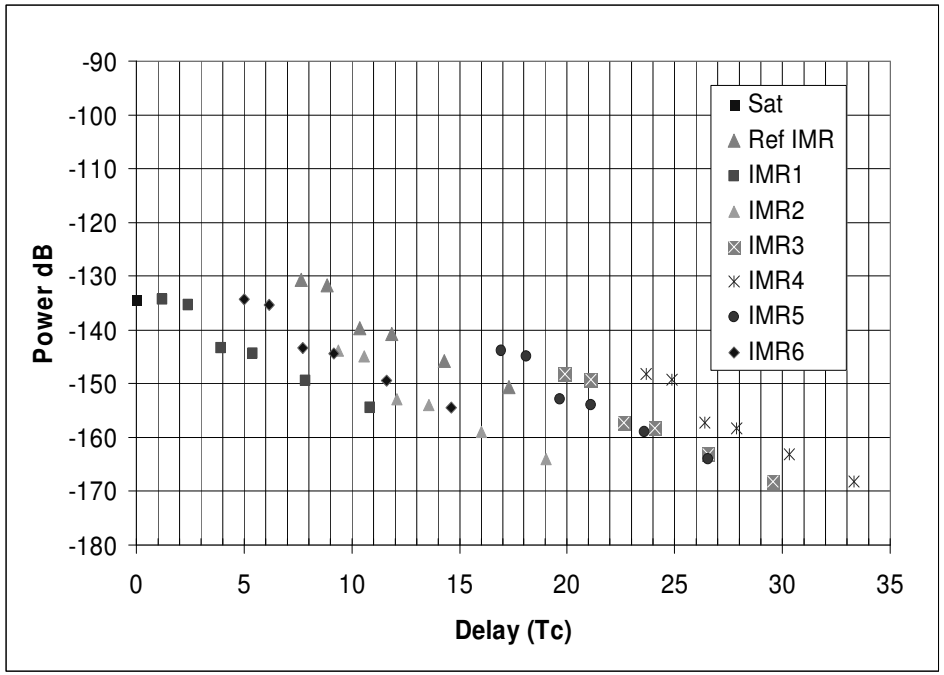
- Low Power IMR (Lat. 51 North, *d* = 1)



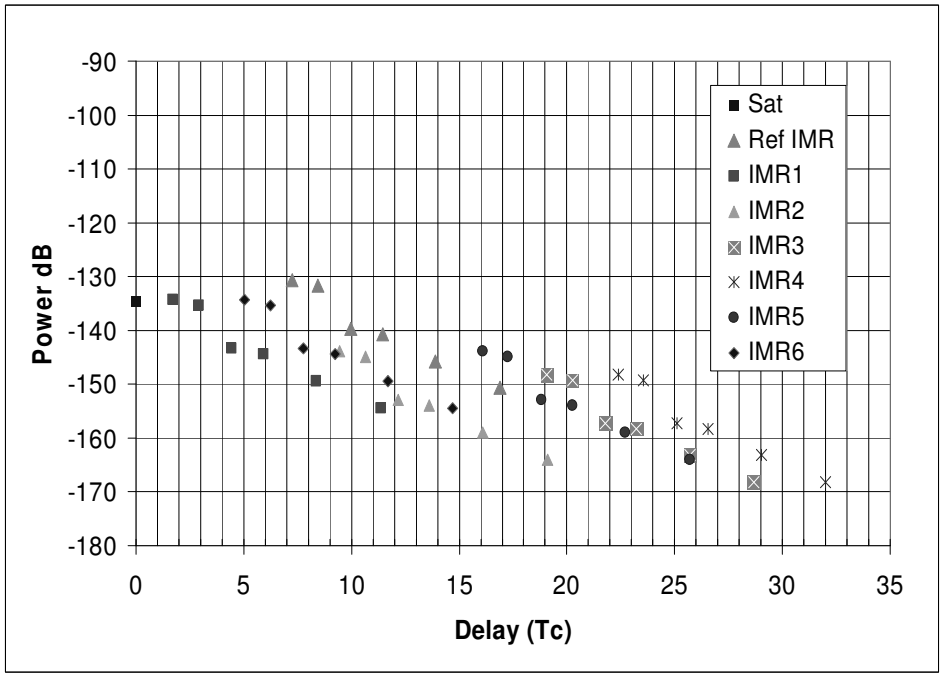
- At d=1 the UE is at the same distance from three IMRs
  - same intensity of the three corresponding signal replicas
  - different delays due to different distances from the GEO satellite and the IMRs

Power delay profile
variation as a function of latitude

- Low Power IMR (Lat. 51 North, *d*=0.86)



- Low Power IMR (Lat. 42 North, *d*=0.86)

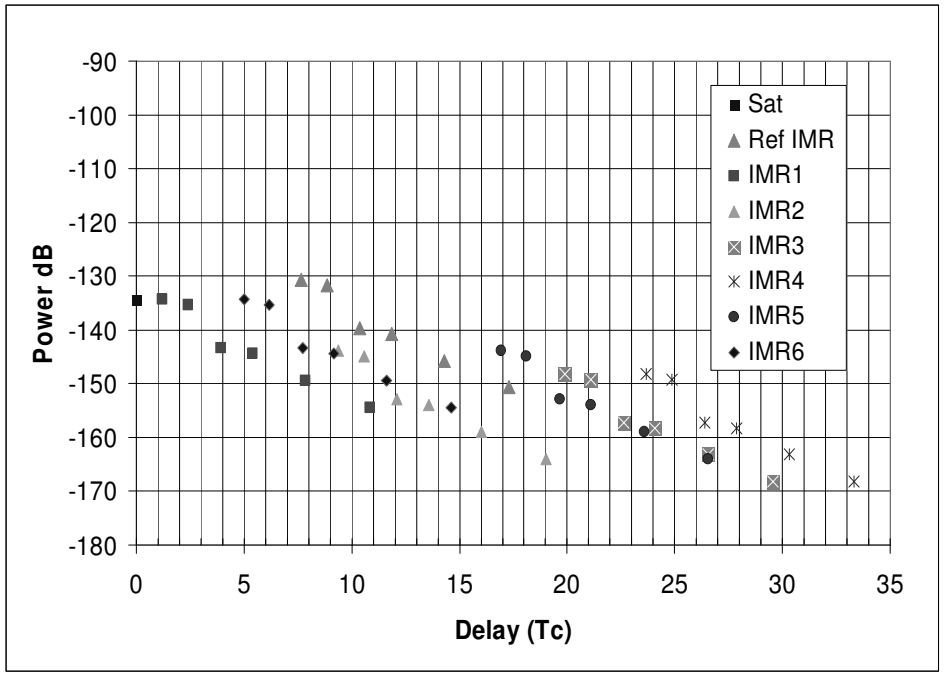


- Lat. 51 (Central Europe) vs. Lat. 42 (Rome): only limited differences
  - The delay spread is reduced of a chip time at 42

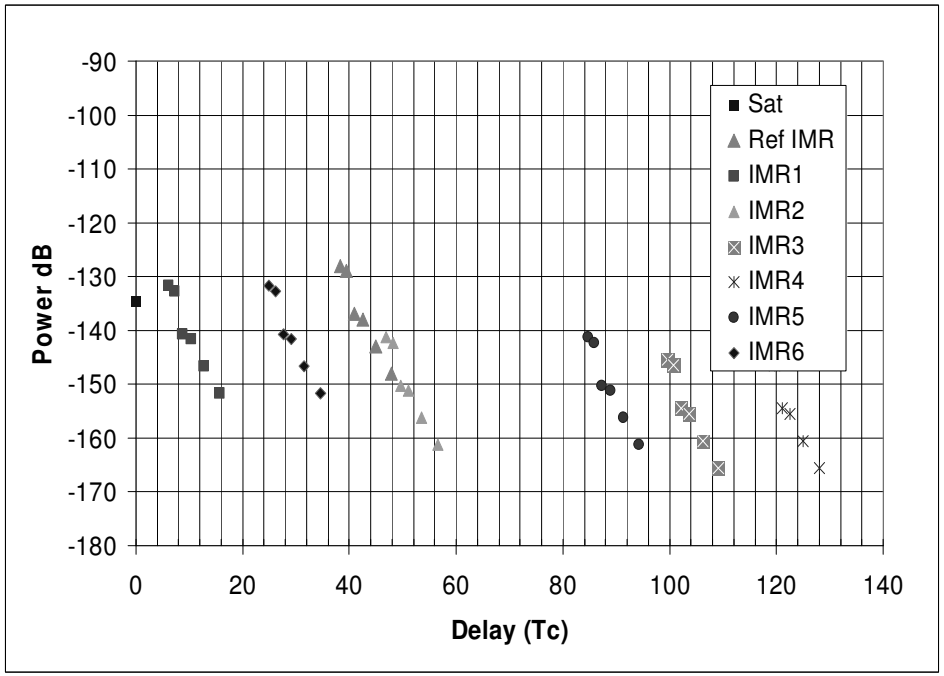
Power delay profile

variation as a function of the IMR characteristics

- **Low Power IMR (Lat. 51 North, *d*=0.86)**



- **High Power IMR (Lat. 51 North, *d*=0.86)**



- **Due to the larger distances involved, satellite replicas coming from different IMRs are separated in time**
  - **the overall delay spread is largely increased**

Discussion

- With respect to a single IMR (ETSI vehicular channel), the delay spread increases by a factor that goes from 3 to 10, depending on the IMR power and coverage radius
- Spread spectrum transmission provides:
  - Interference immunity
  - Multipath immunity

  ... but the improvement in SNR is linear with the spreading factor
- The Rake receiver collects and combines energy from the available fingers. Many fingers with large epoch-agility are required
- The uncertainty region for code acquisition becomes huge, and multipath clusters may be very sparse
- Considering Doppler spread, tracking fingers may become a problem. Asymptotically, as the number of degrees of freedom goes to infinity, the capacity of CDMA vanishes!
- What about UWB systems?