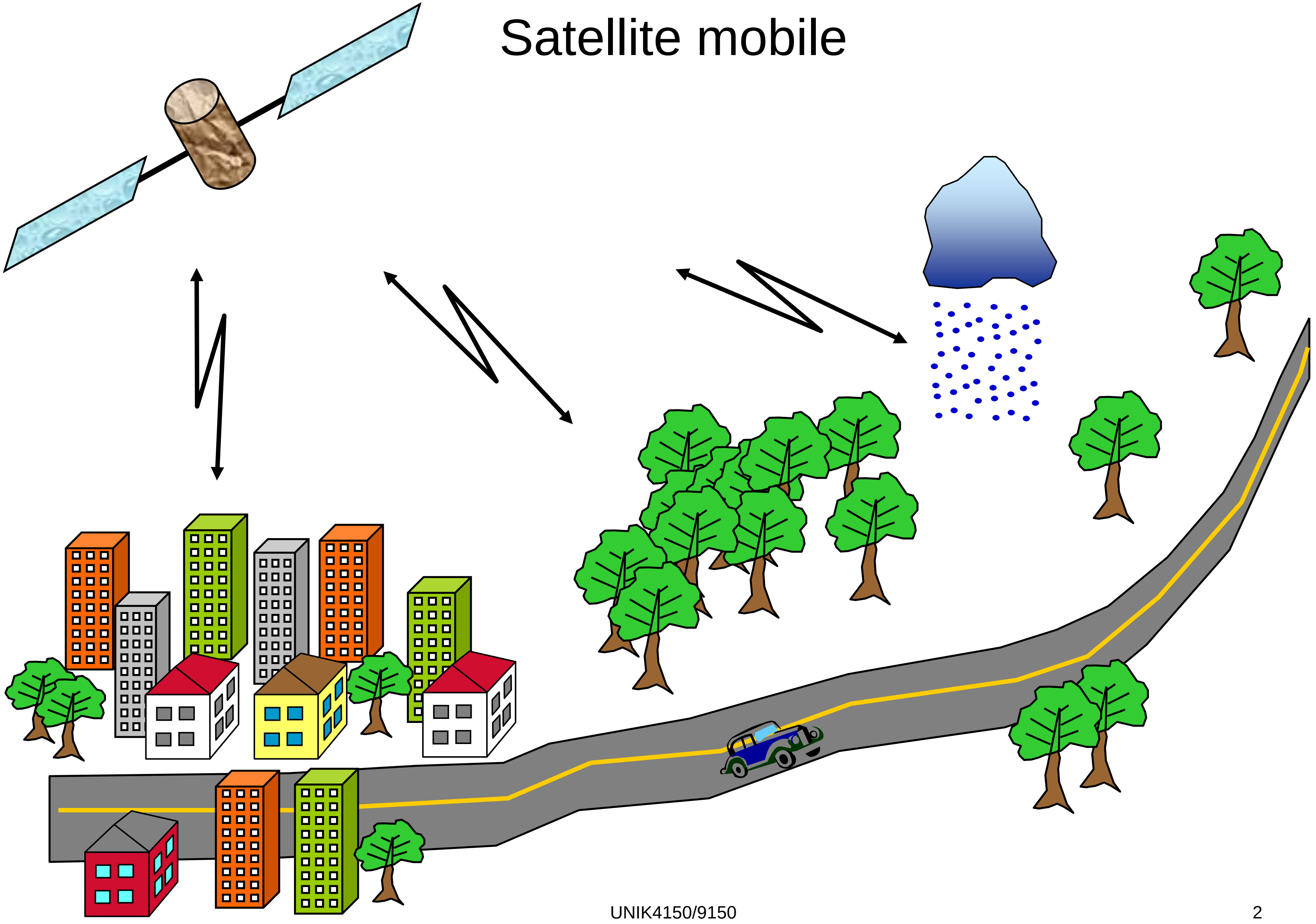
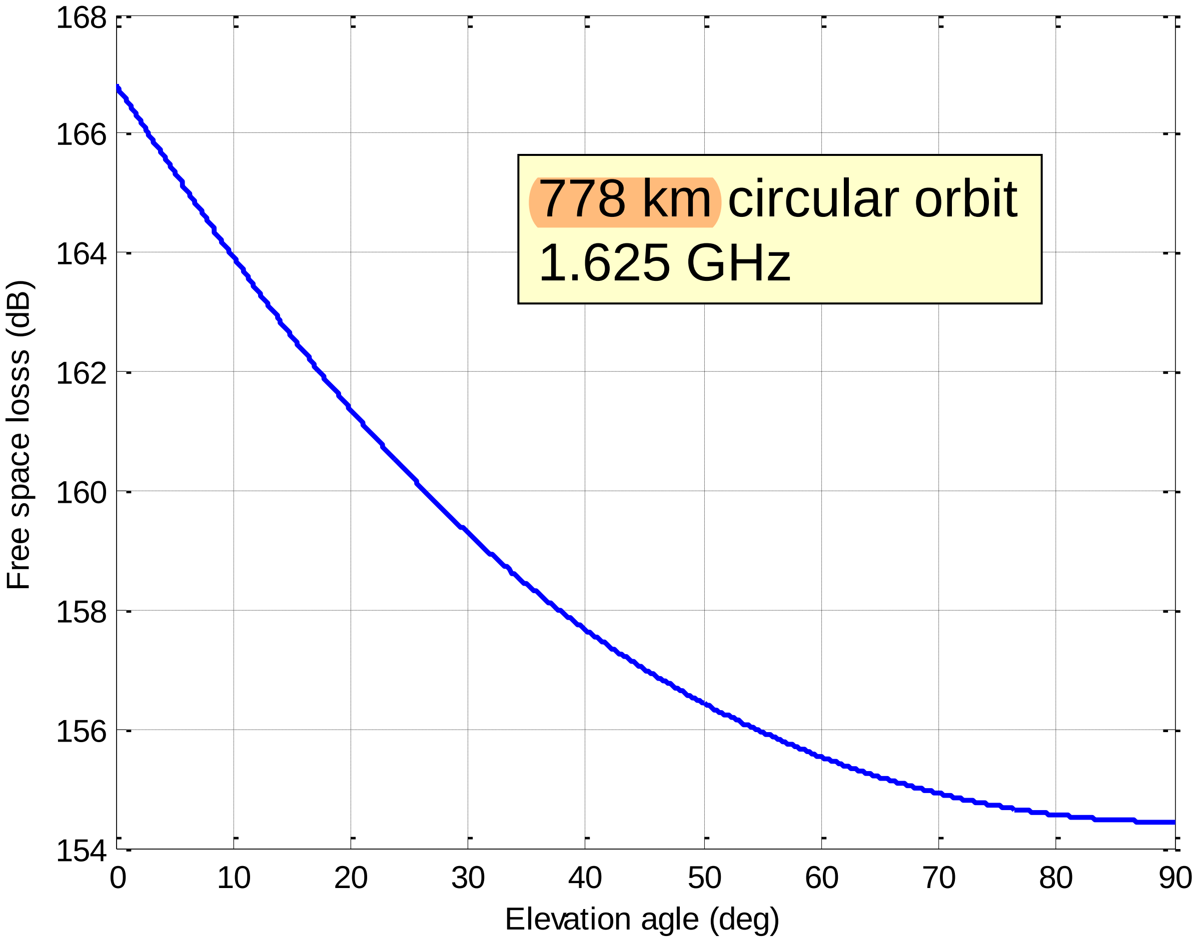
Chapter 14 Megacells

- Mobile satellite systems
  - Global service
  - Land, sea, air
  - GEO, LEO, ICO
- Shadowing and fast fading
- Narrowband and wideband
- Statistical and physical models
- Multi-state modelling

Satellite mobile

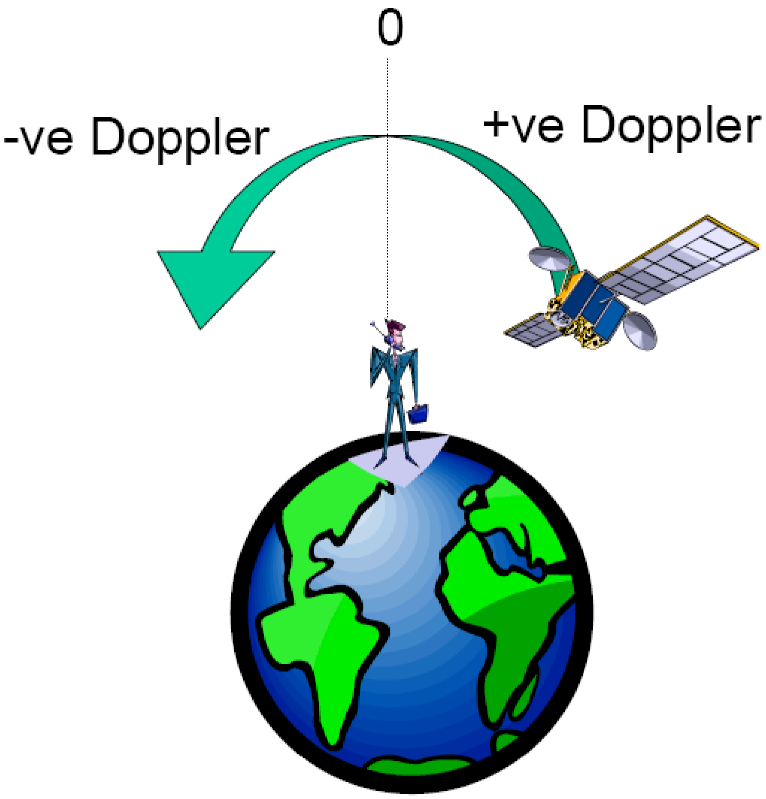


Free space loss for a LEO satellite



Doppler shift

- Doppler shift only since the satellite passes following one direction and there is not scattering included
- No Doppler spread
- Simple to compensate or tune the receiver



Local sources for propagation caused impairment

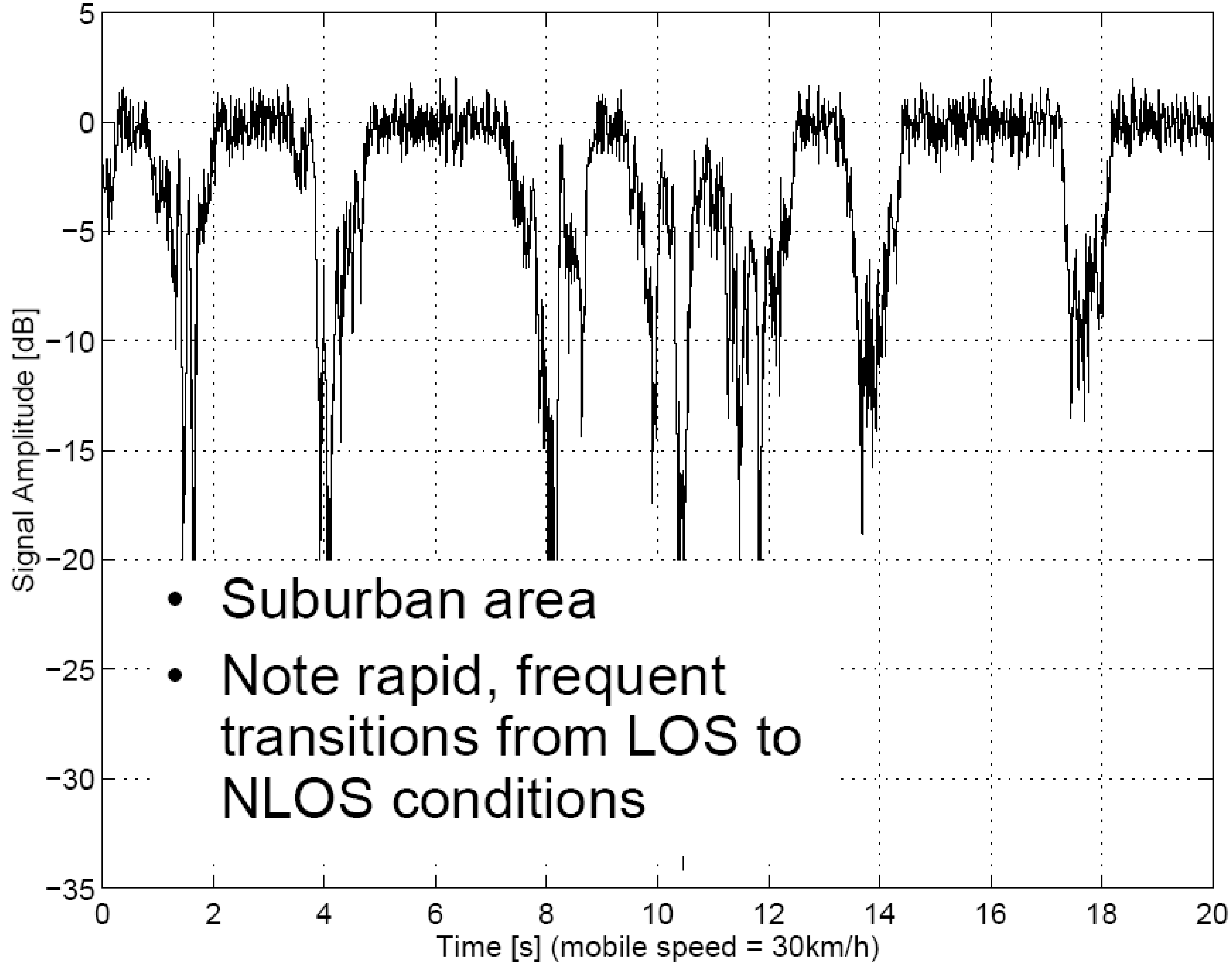
Local sources:

- Trees
- Buildings
- Terrain

Mechanisms:

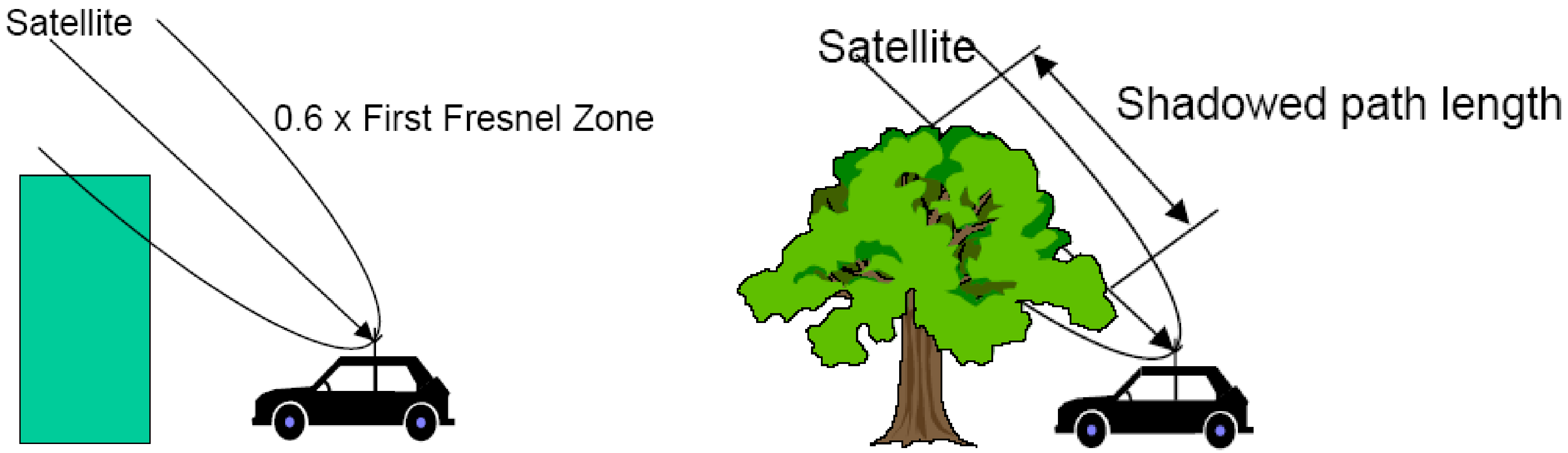
- Reflection
- Scattering
- Diffraction
- Multipath

Signal variations



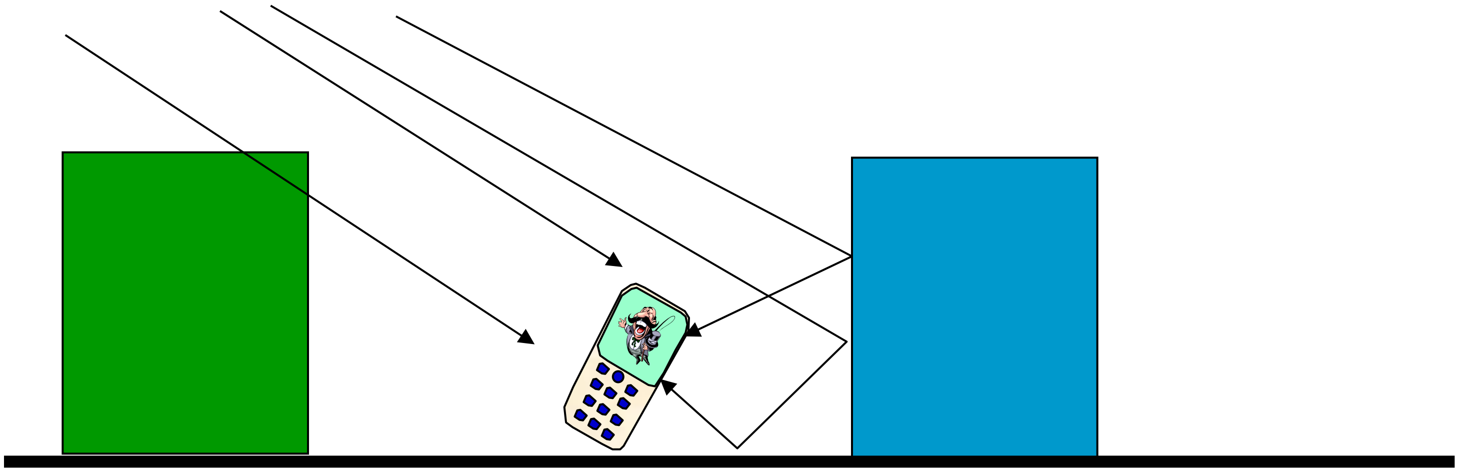
- Suburban area
- Note rapid, frequent transitions from LOS to NLOS conditions

Shadowing



- Roadside buildings produce significant attenuation when > 0.6 x first Fresnel zone blocked
- Trees produce attenuation around 1.7dB/m at 900 MHz

Multipath



- Reflections and rough surface scattering produces multipath and hence fast fading
- Path length differences small, so wideband effects modest
- Multiple scattering weak (e.g. satellite-x-y) Satellite

Empirical roadside shadowing model

Predict the probability of fading to a given depth in presence of roadside trees

ITU-R method at 1.5 GHz (Rec. P.681)

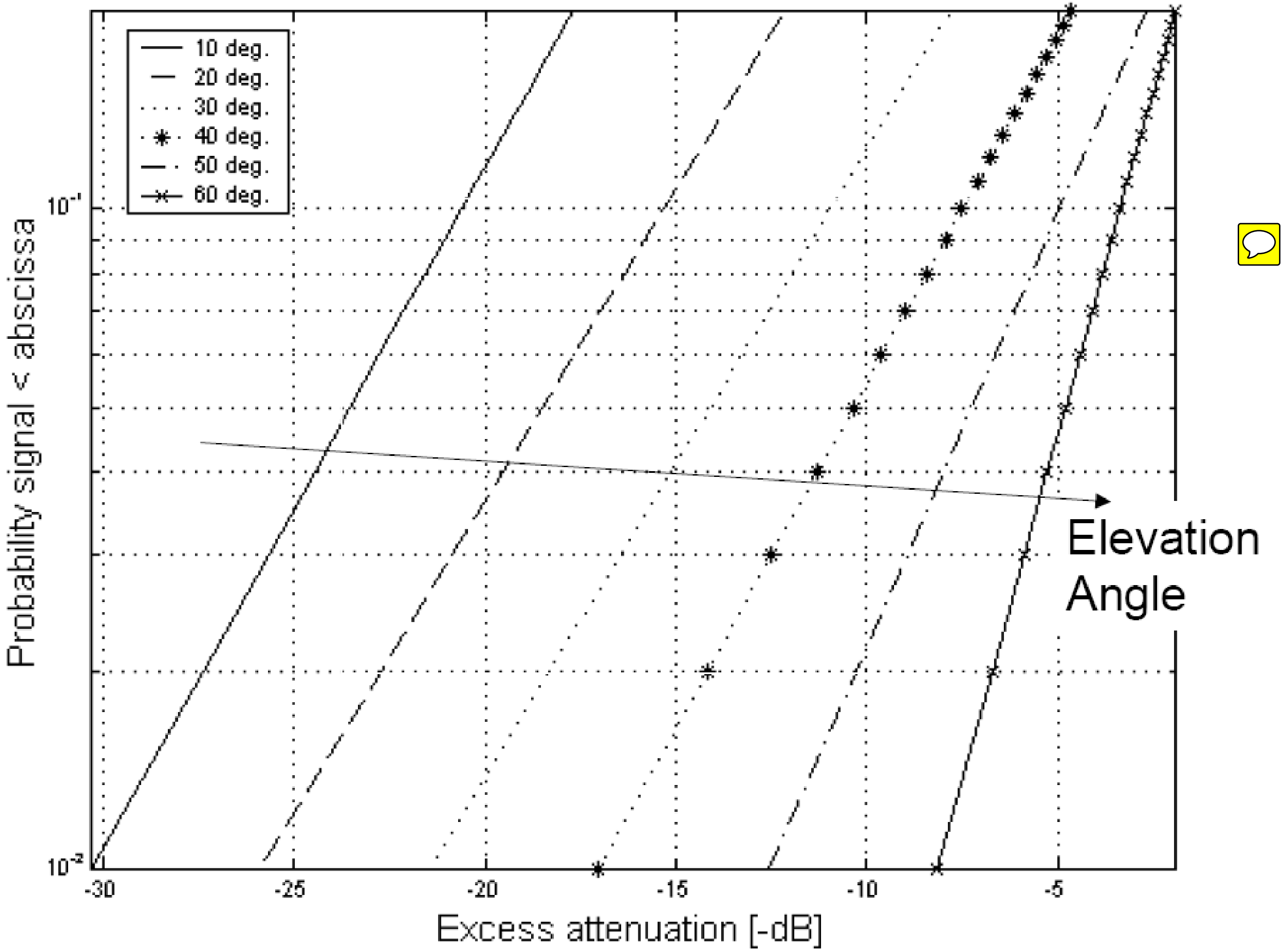
$$L(P,\theta) = -\left(3.44 + 0.0975\theta - 0.002\theta^2\right)\ln P + \left(-0.443\theta + 34.76\right)$$

where *P* is percentage of distance and θ elevation angle

Extend to the range 0.8-20 GHz

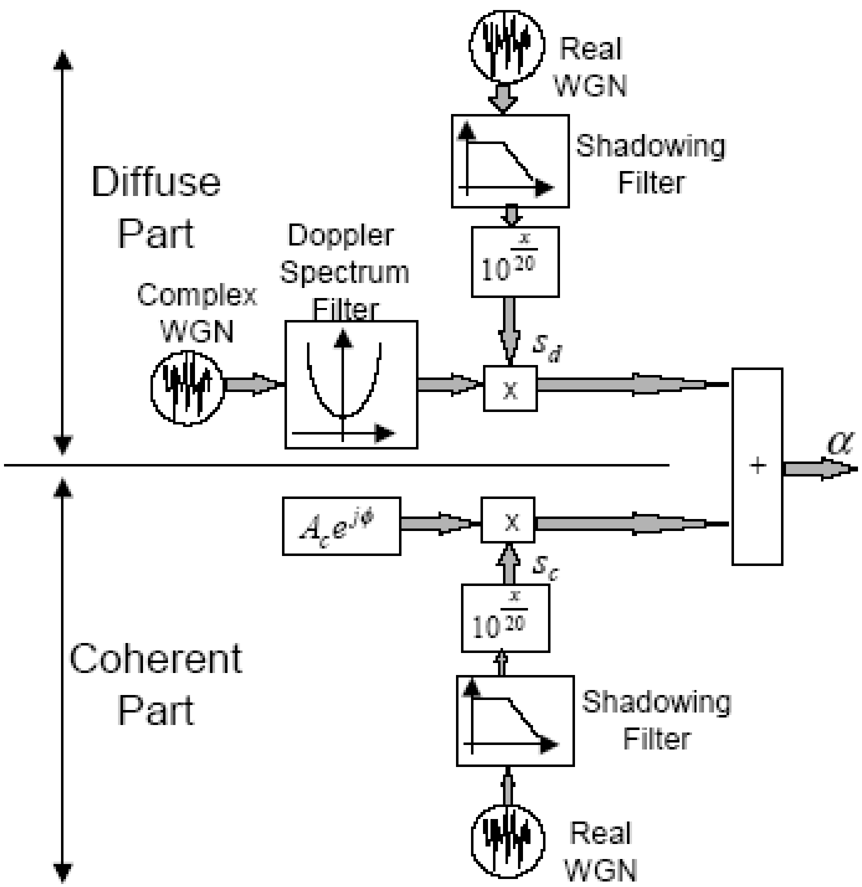
$$L(f_2) = L(f_1)e^{1.5\left(\frac{1}{\sqrt{f_1}} - \frac{1}{\sqrt{f_2}}\right)}$$

Empirical roadside shadowing (ERS) model predictions



Coherent Diffuse

$$\alpha = A_c s_c e^{j\phi} + r s_d e^{j(\theta+\phi)}$$



Statistical model

- Channel statistics using Rice, Rayleigh, and log-normal
- A_C- coherent, s_c and s_d shadowing, r complex Gausian -> amplitude Rayleigh
- Multiplicative channel as sum of coherent (line-of-sight) and diffuse (scattered) parts
- Loo, Corazza, Lutz

Loo model

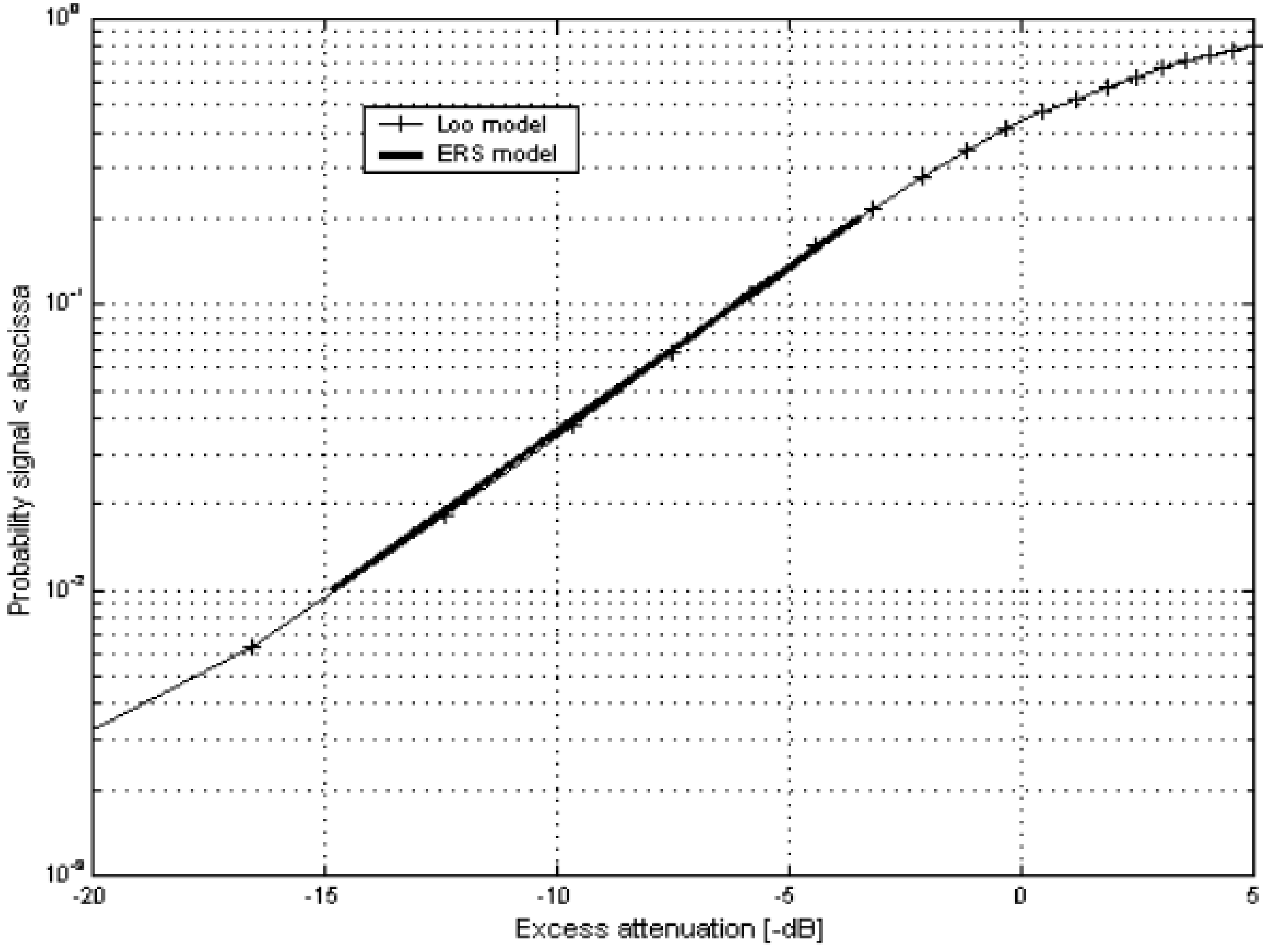
- For tree shadowing
- Coherent part lognormal (*d*)
- Multipath is Rayleigh (*s*)

$$\alpha = de^{j\phi_0} + se^{j\phi}$$

$$r = |\alpha|$$

$$p(r) \approx \begin{cases} \overbrace{\dfrac{r}{\sigma_m^2}\exp\left(-\dfrac{r^2}{2\sigma_m^2}\right)}^{\text{Rayleigh}} & \text{for } r \ll \sigma_m \\ \underbrace{\dfrac{1}{20\log r\sqrt{2\pi\sigma_0}}\exp\left[-\dfrac{(20\log r-\mu)^2}{2\sigma_0}\right]}_{\text{Lognormal}} & \text{for } r \gg \sigma_m \end{cases}$$

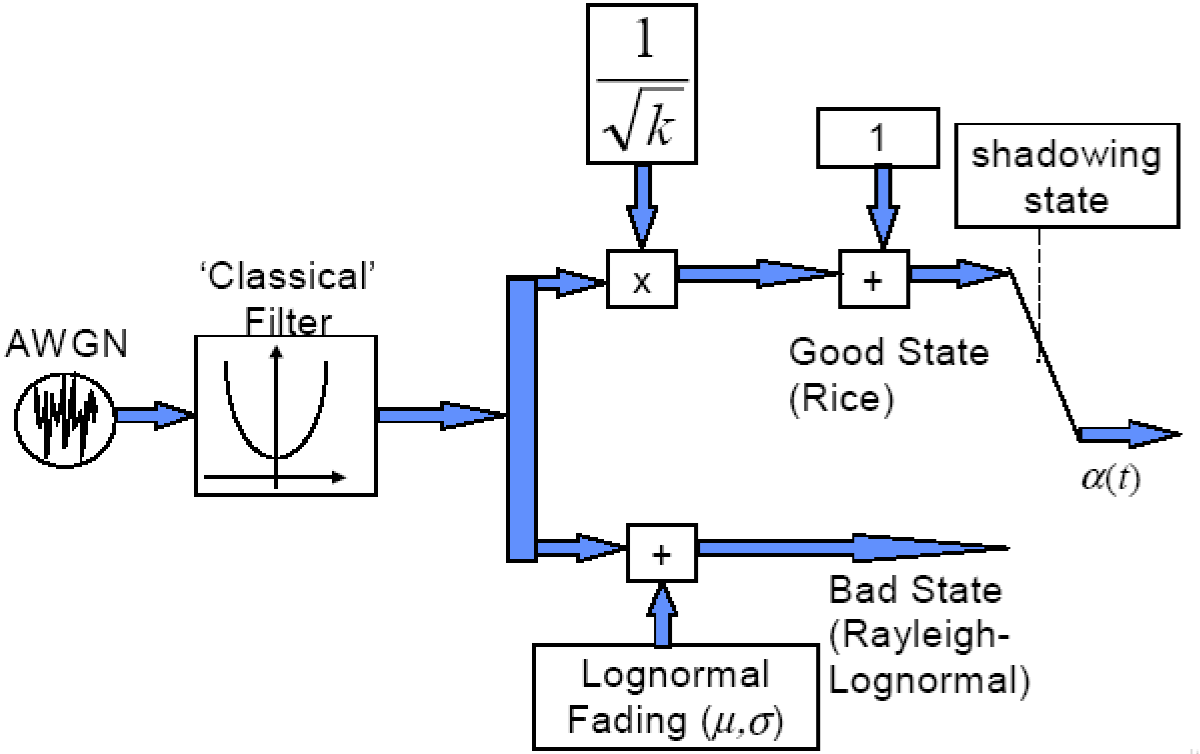
Loo versus ERS



1.5 GHz
45°elevation
σ_m = 0.3
σ_0=5
μ=0.1

Lutz model

- Two distinct channel states
- Distinct statistics in each state

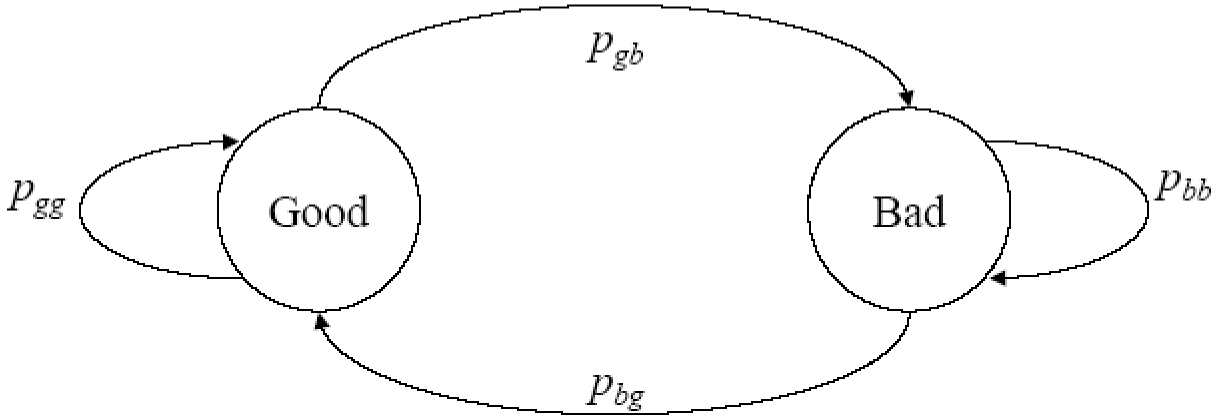


Lutz statistics

- Good state: $p_{good}(r) = p_{rice}(r)$
- Bad state: $p_{bad}(r) = \int_0^\infty p_{rayl}(r \mid S_0) p_{LN}(S_0) dS_0$
- Overall: $p_r(r) = (1 - A) p_{good}(r) + A p_{bad}(r)$
- A is the time-share of shadowing

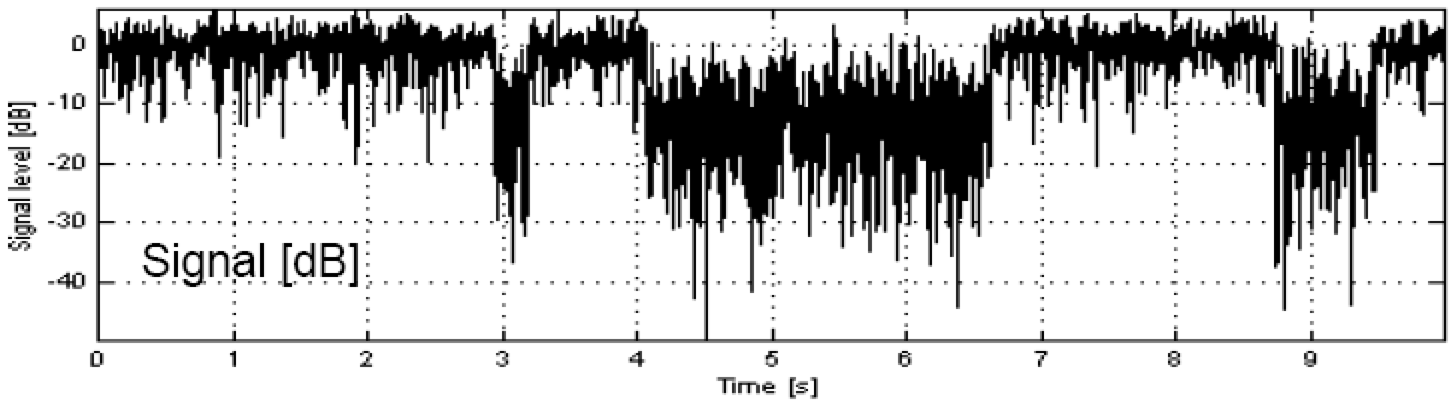
Markov model of channel state

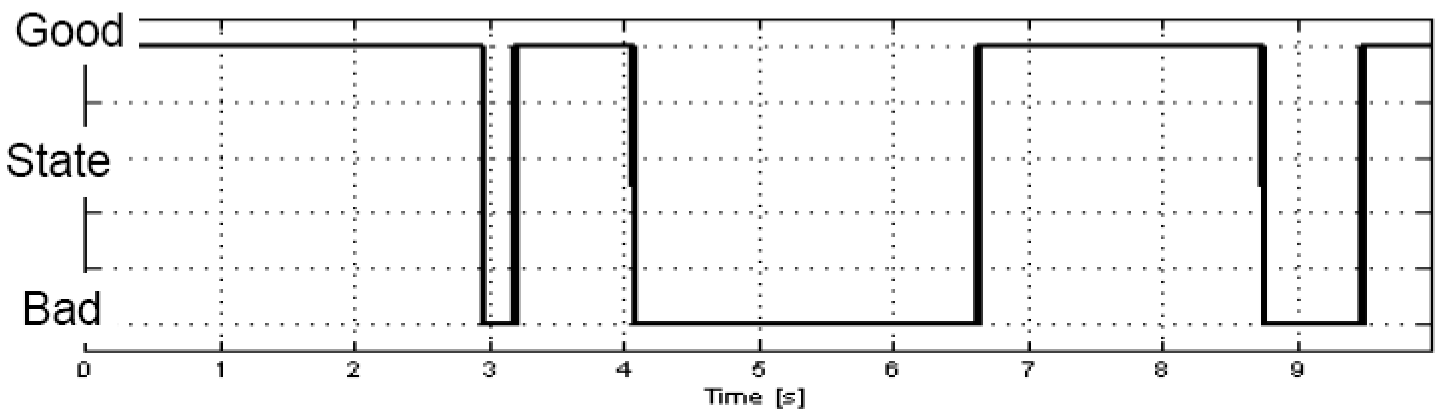
Represents variations between states by transition probabilities



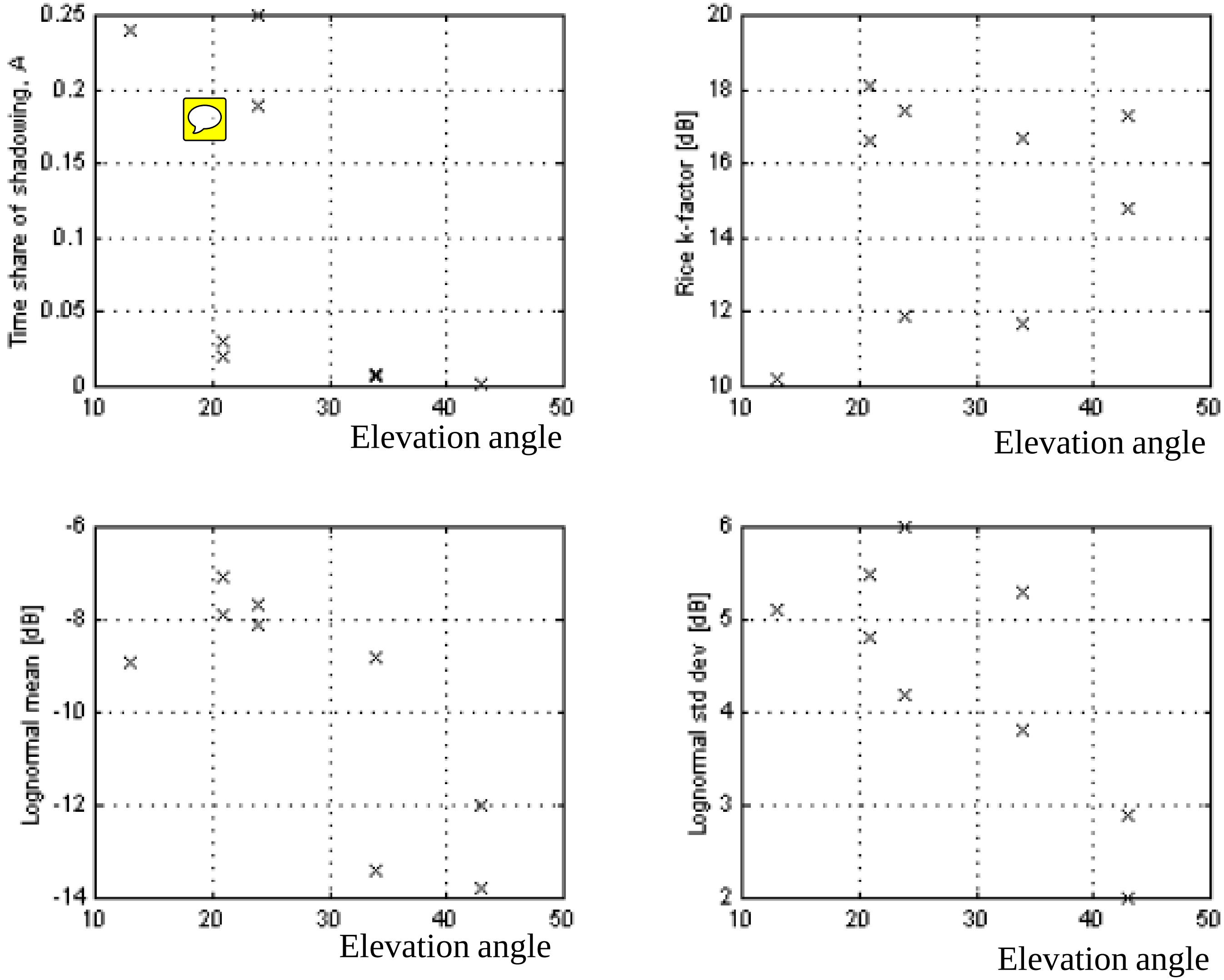
$$p_{gg} = 1 - p_{gb} \text{ and } p_{bb} = 1 - p_{bg}$$

Time series example

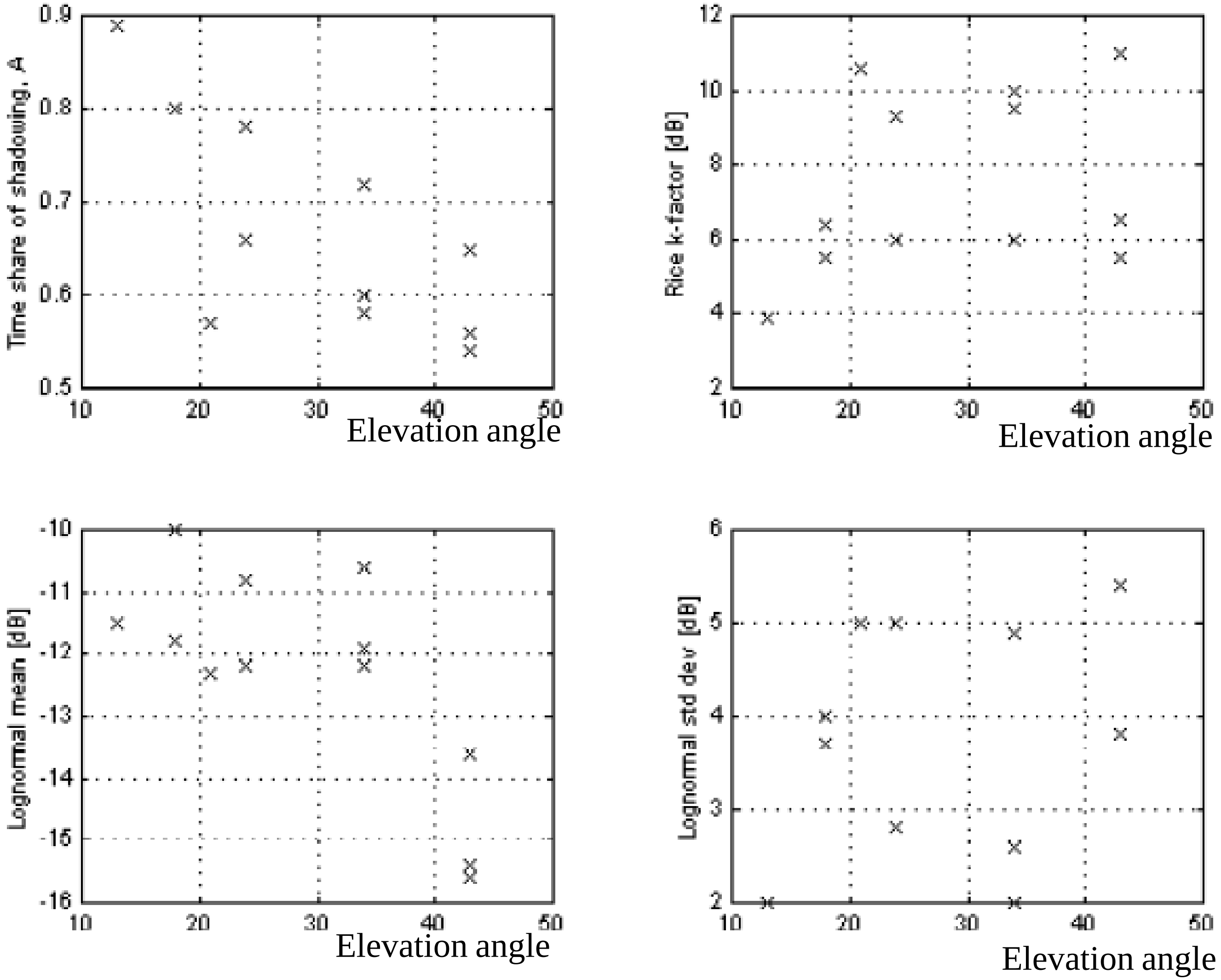




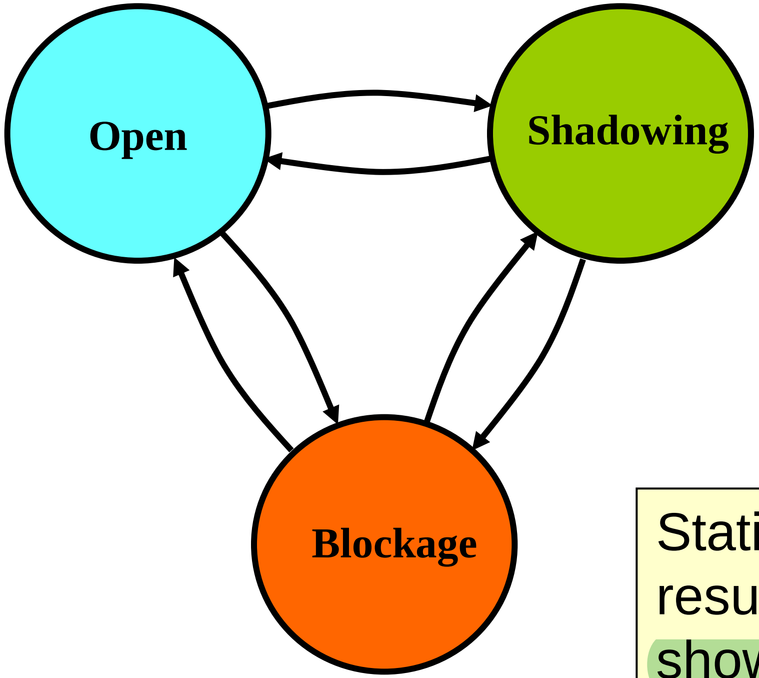
Lutz model parameters for highway



Lutz model parameters for city



Semi-Markov multi-state model



Statistical models of each state and resulting in a cumulative distribution showing a combination of effects.

Building height distribution

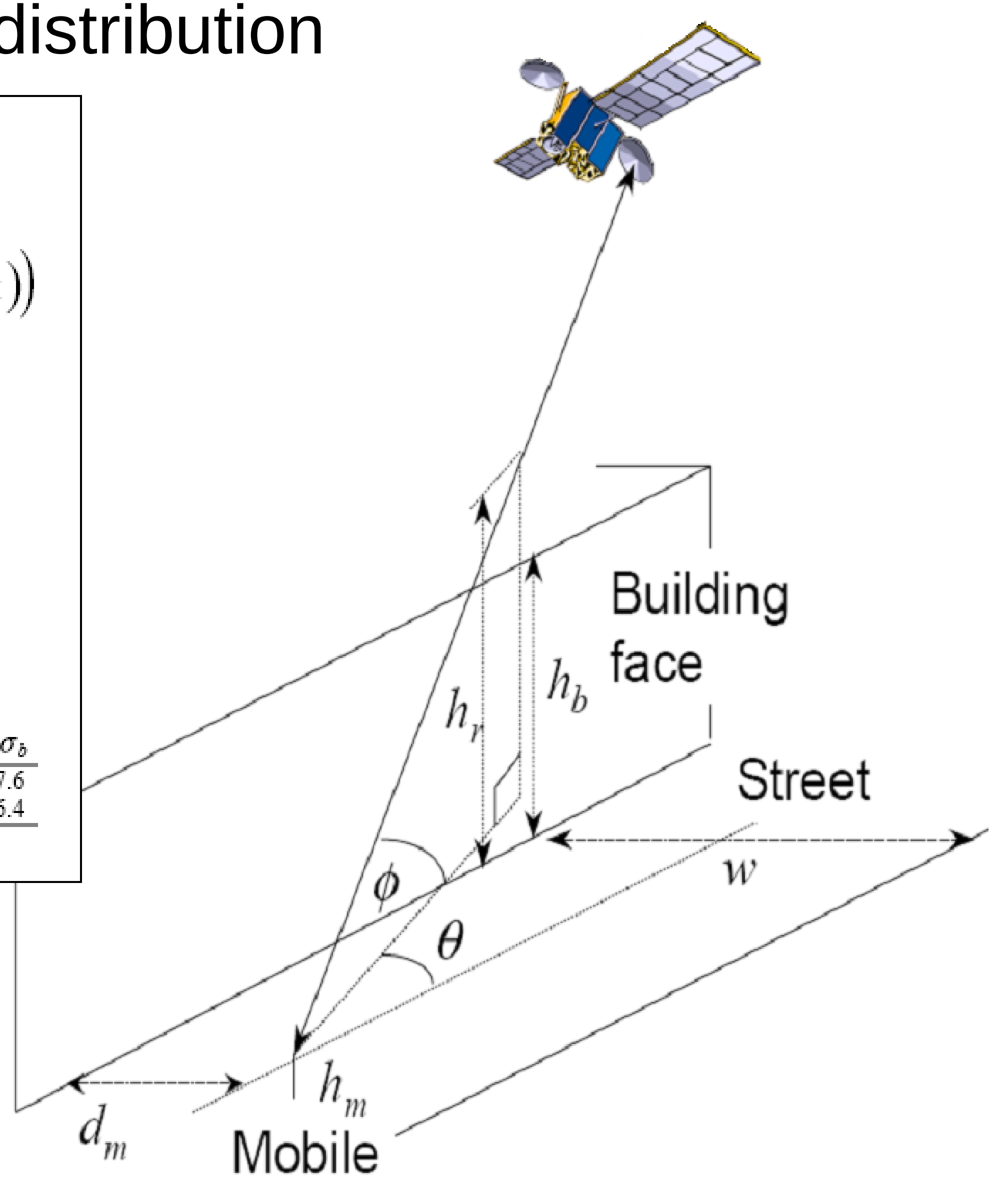
- Log-normal:

$$p_b(h_b) = \frac{1}{h_b\sqrt{2\pi}\sigma_b}\exp\left(-\left(1/2\sigma_b^2\right)\ln^2\left(h_b/\mu\right)\right)$$

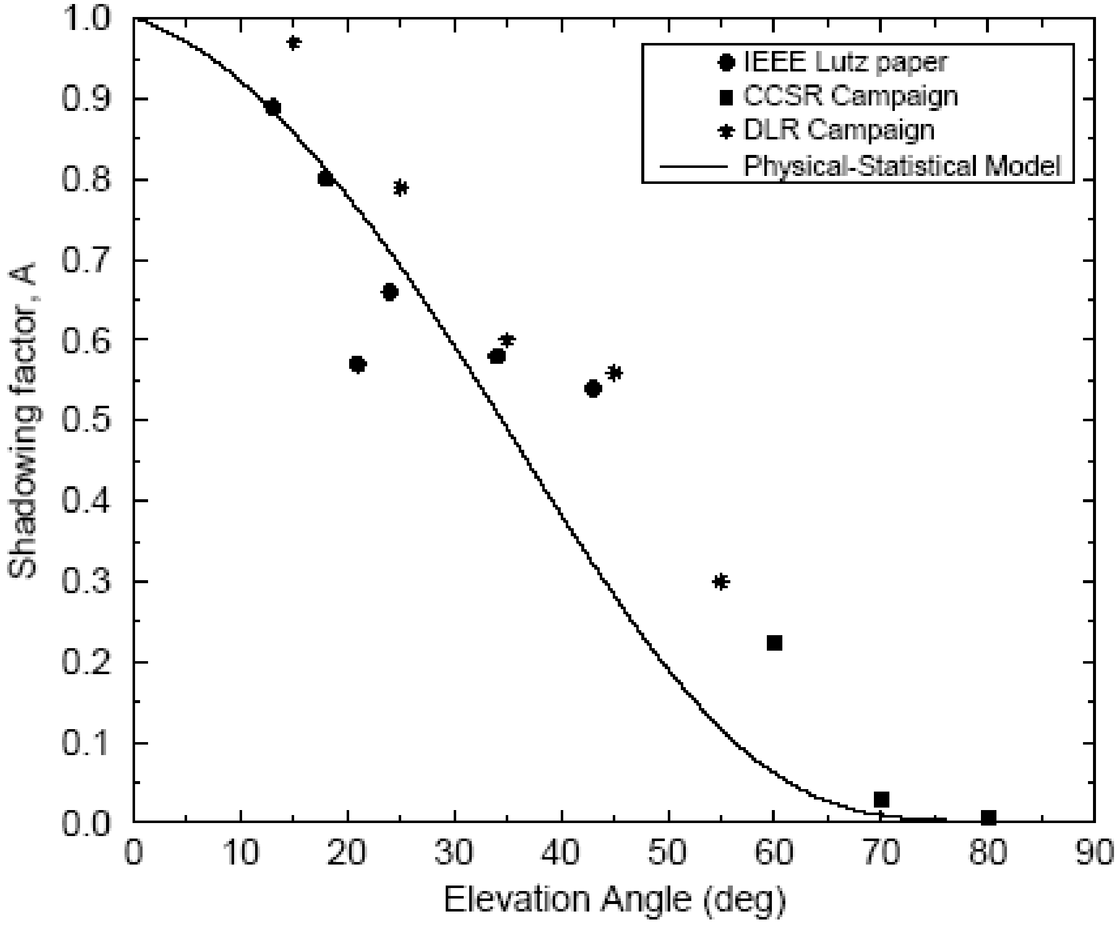
- Rayleigh:

$$p_b(h_b) = \frac{h_b}{\sigma_b^2}\exp\left(-h_b^2/2\sigma_b^2\right)$$

City	Log-normal p.d.f. Mean μ	Log-normal p.d.f. Standard deviation σ_b	Rayleigh p.d.f. Standard deviation σ_b
Westminster	20.6	0.44	17.6
Guildford	7.1	0.27	6.4



City and sub-urban time share for shadowing



Conclusions

- Megacell channels a relatively new field; apparently more considered a few years ago
- Same physics as for terrestrial, but noting
  - Large distance to satellite
  - Elevation angles are much more important
- Effects of the troposphere and ionosphere are the same as for fixed satellite systems

Chapter 17 Overcoming wideband fading

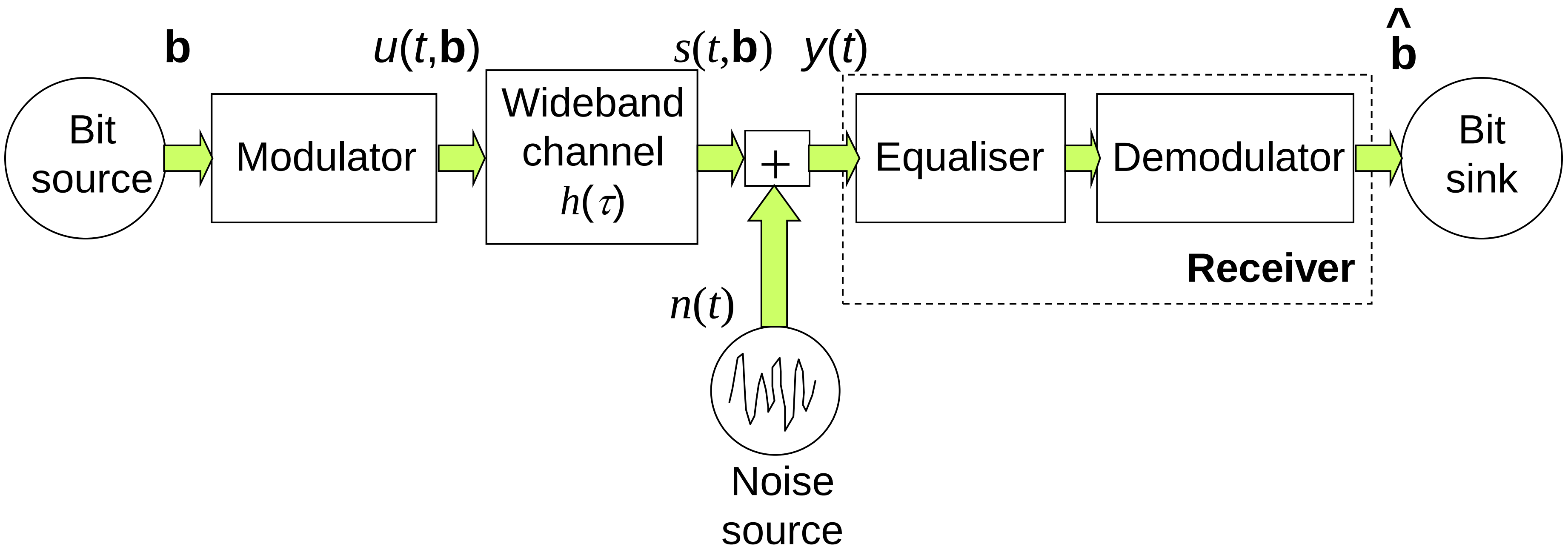
- Previous chapter narrowband fading channel techniques, although antenna diversity also works for wideband
- More advanced techniques to exploit the frequency diversity potential
- Three broad techniques depending on modulation and multiple access scheme
  - For TDMA and single user improvement with equaliser
  - For CDMA improvement with Rake receiver
  - For OFDMA improvement partly via the receiver structure

System model for receiver with equaliser

$\mathbf{b}=[b_0,b_1,\ldots,b_{m-1}]$, $b_i=\pm 1$

$s(t,\mathbf{b})=u(t,\mathbf{b})*h(\tau)$

$y(t)=s(t,\mathbf{b})+n(t)$



Continuous waveform sampled at symbol interval *T*

Discrete values $\{y_k\}$ sampled at symbol time intervals T

$$y_k = y(t_0 + kT)$$
$$= s_k + n_k$$

The discrete channel has 2D+1 taps

$$s_k = \sum_{j=-D}^{D} h_j u_{k-j}$$

The received signal expressed as a sum of the desired signal, the intersymbol interferences (ISI) resulting from the delay spread, and noise

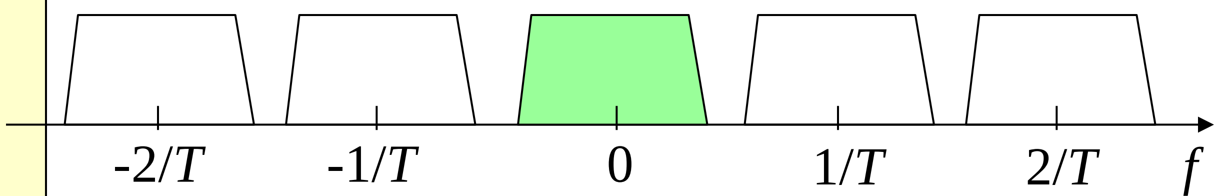
$$y_k = u_k h_0 + \sum_{\substack{-D \le j \le D \\ j \ne 0}} h_j u_{k-j} + n_k$$

desired ISI noise

ISI is zero, first Nyquist criterion

The narrowband case of only one single tap gives ISI = 0, but also if ISI is zero at sampling points $t = t_0 + kT$. Then the channel obeys the *first Nyquist criterion*. The transfer function can then be calculated as below.

The spectrum of the discrete signal is periodic. The spectrum of received waveform *y(t)* is *Y*(*f*), sampled version $Y_a(f)$, and the received signal is the inverse Fourier transform, signal with bandwidth W.



$$Y_a(f) = \sum_{N=-\infty}^{\infty} Y\left(f + \frac{n}{T}\right)$$

$$y_k = y(kT + t_0) = \int_{-W/2}^{W/2} Y_a(f) e^{j2\pi fkT} df$$

Zero ISI requires for y_0 and y_k

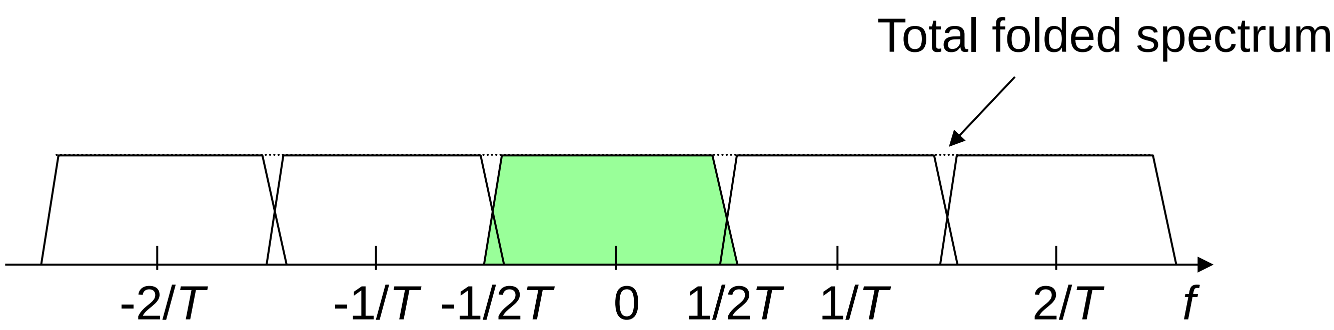
$$y_0 = \int_{-W/2}^{W/2} Y_a(f) df = 1$$

$$y_k = y(kT + t_0) = \int_{-W/2}^{W/2} Y_a(f) e^{j2\pi fkT} df = 0 \quad \text{for} \quad k \neq 0$$

Hence $Y_a(f) = Y_a$ for all f.

First Nyquist criterion

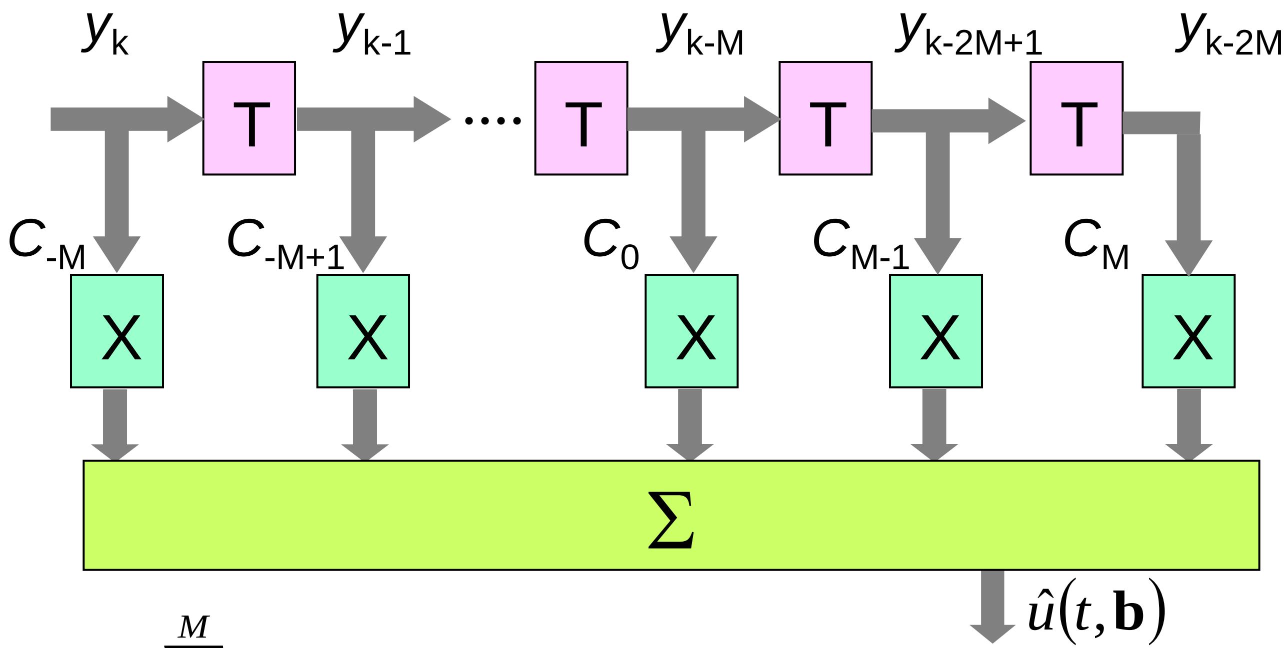
Can only happen if the aliased spectrum components fill the gaps: Signal spectrum must have odd symmetry around $f = 1/2T$.



Usually achieved by distributing the transmit and receive filters such that their common transfer function satisfied the criterion. On example is the a filter called *root-raised cosine*.

Simple linear equalisers

Transverse filter with $2M+1$ coefficients. Symbol spaced intervals T, but even better performance with fractional spaced intervals. Coefficients C chosen to best combat adverse effects.



$$\hat{u}_k = \sum_{i=-M}^{M} c_i y_{k-i}$$

$$\hat{u}_k = \underbrace{u_k c_0 h_0}_{\text{desired}} + \underbrace{\sum_{\substack{-M \le i \le M \\ i \ne 0}} \sum_{\substack{-D \le j \le D \\ j \ne 0}} h_j c_i u_{k-j}}_{\text{ISI}} + \underbrace{\sum_{i=-M}^{M} c_i n_{k-i}}_{\text{noise}}$$

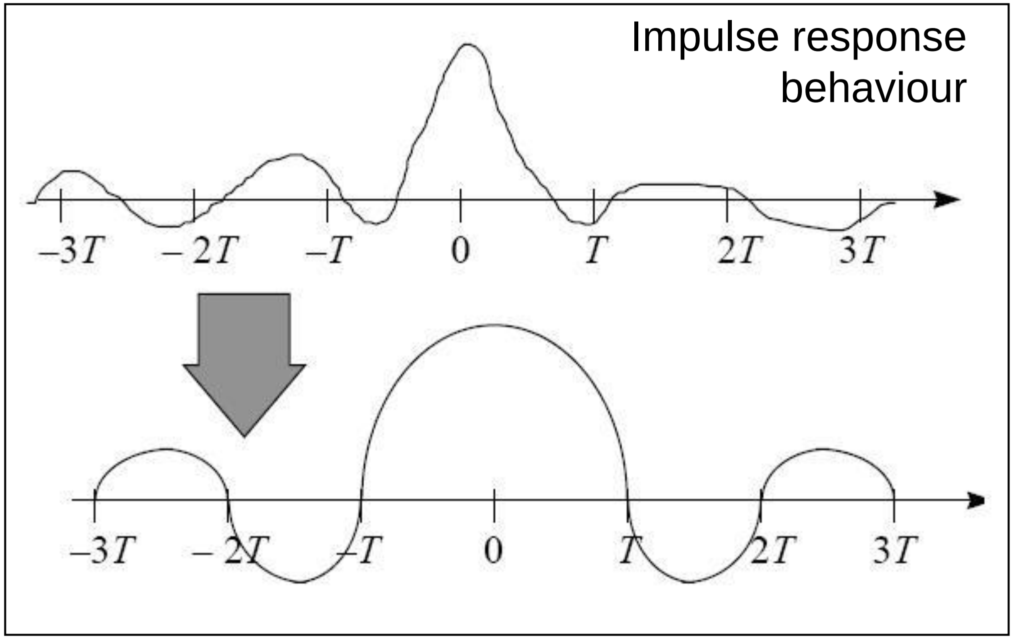
Zero-forcing equalisers

Unlikely that first Nyquist criterion is met. Therefore the coefficients are chosen to do this, i.e. ISI terms set to zero.

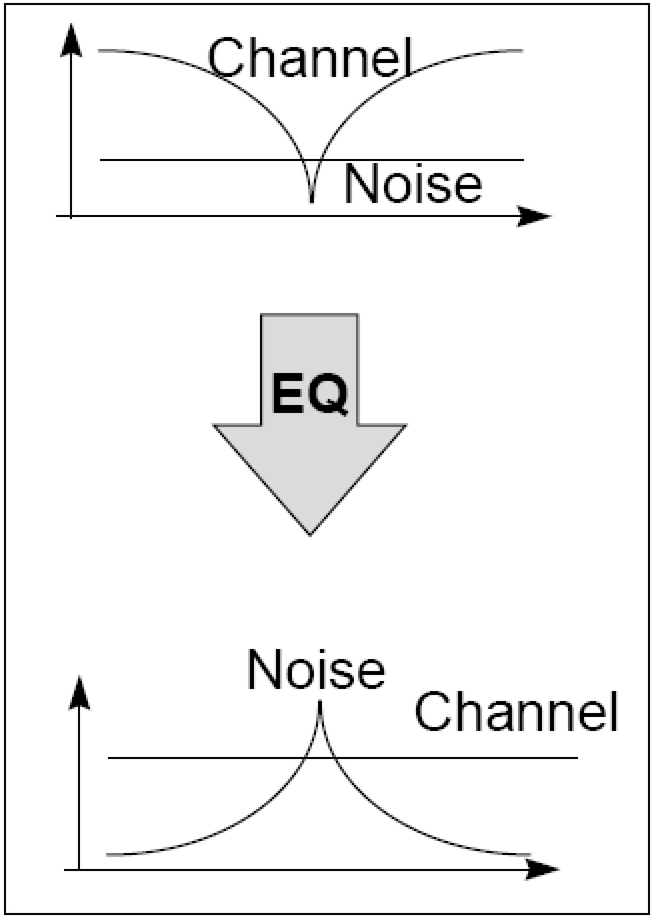
$$\sum_{\substack{-M \le i \le M \\ i \ne 0}} \sum_{\substack{-D \le j \le D \\ j \ne 0}} h_j c_i u_{k-j} = 0$$

The folded spectrum of channel $H_a(f)$ and equaliser $C(f)$

$$C(f)H_a(f) = \begin{cases} T & |f| \le \frac{1}{2T} \\ 0 & |f| > \frac{1}{2T} \end{cases}$$



Problems with Zero-forcing equaliser



The frequency response of the equaliser is the inverse of the channel. However, this method may enhance noise and lead to undesirable low signal-to-noise ratio at output. Solution might be to use least mean squares minimising the total disturbance.

Least mean square equaliser

- Minimises total disturbance consisting of all the ISI and the noise
- Estimate channel, then compute Wiener solution directly
- Size of matrix, and hence computation time, grows rapidly with length of equaliser

$$J = E\left[\left|u_k - \hat{u}_k\right|^2\right] = E\left[\left|u_k - \sum_{i=-M}^{M} c_i y_{k-i}\right|^2\right]$$

solved by choosing c_i to minimze J

$$\mathbf{c} = \mathbf{R}_{yy}^{-1}\mathbf{r}_{yu} \quad \text{(the Wiener solution)}$$

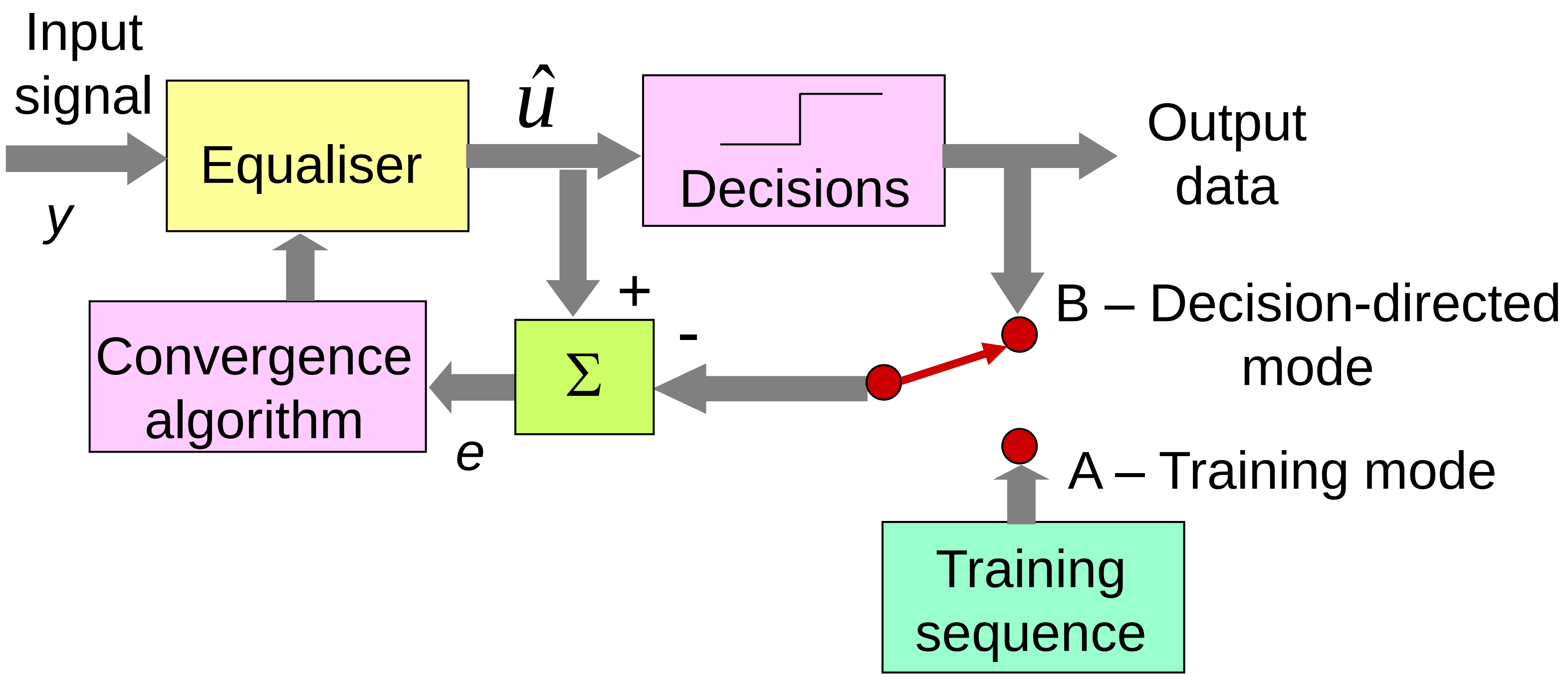
where $\mathbf{R}^{-1}$ is the inverse correlation matrix of the vector of inputs to the filter

$$\mathbf{R}_{yy} = E\left[\mathbf{y}(k)\mathbf{y}^H(k)\right], \quad \mathbf{y}(k) = \left[y_k, y_{k-1}, \ldots, y_{k-2M}\right]^T \quad \textit{and} \quad \mathbf{r}_{yu} = E\left[\mathbf{y}(k)u_k^*\right]$$

(^{H} Hermittian, or transposed complex conjugate, ^{T} transposed vector)

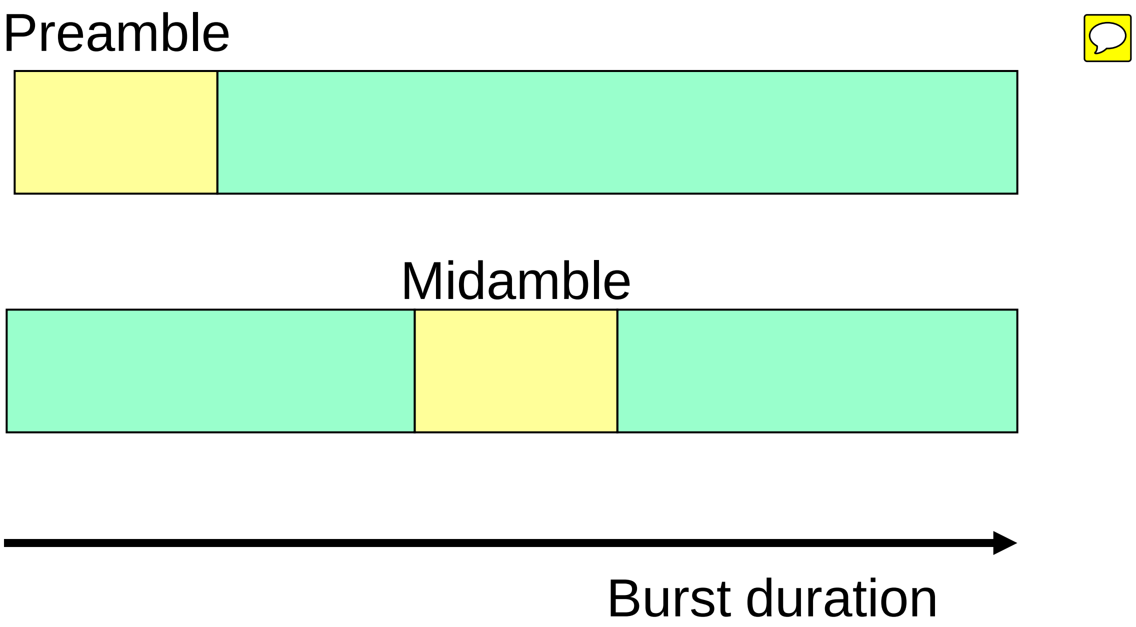
Adaptive equalisers

The channel varies with time and coefficients have adaptively to be chosen. An algorithm is used to find the optimum coefficients, called *convergence* algorithm.



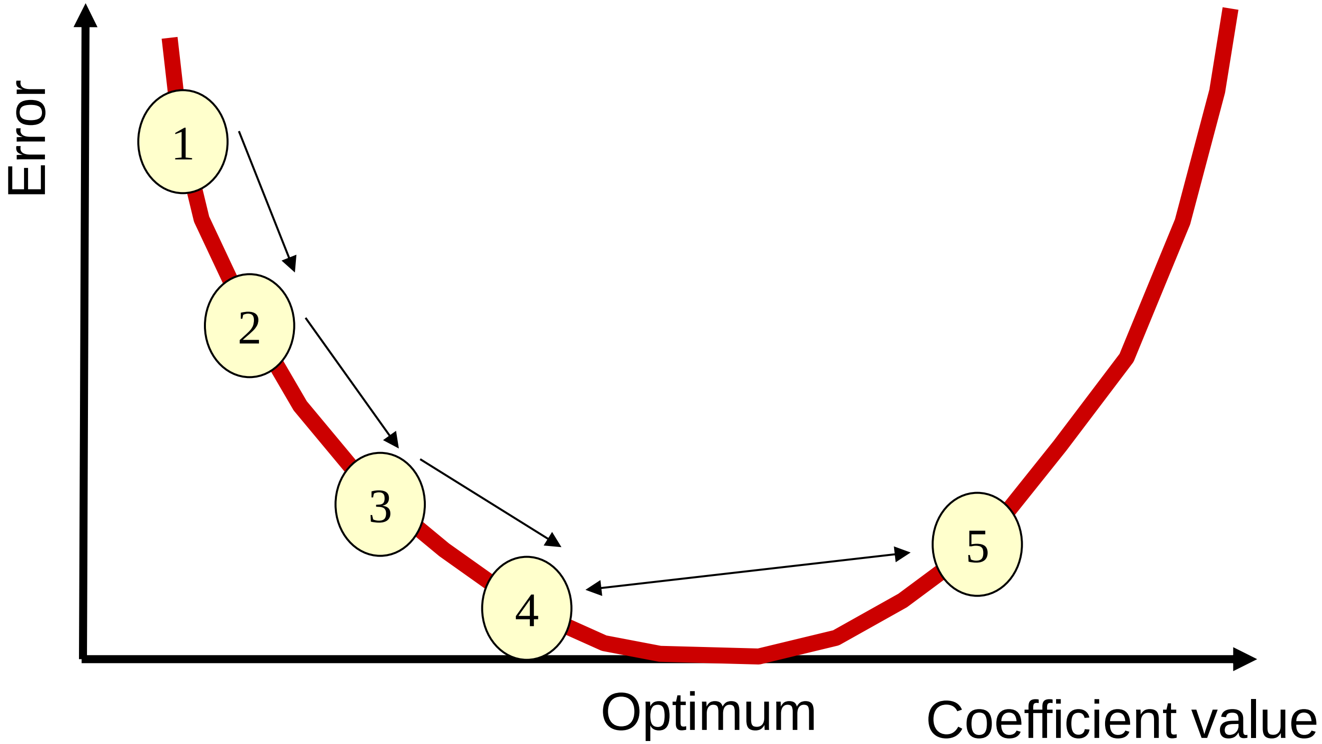
Burst data used for training

Many practical systems send data in bursts. A training sequence can then be part of the burst, e.g., as preamble or midamble. Also blind algorithms are used.



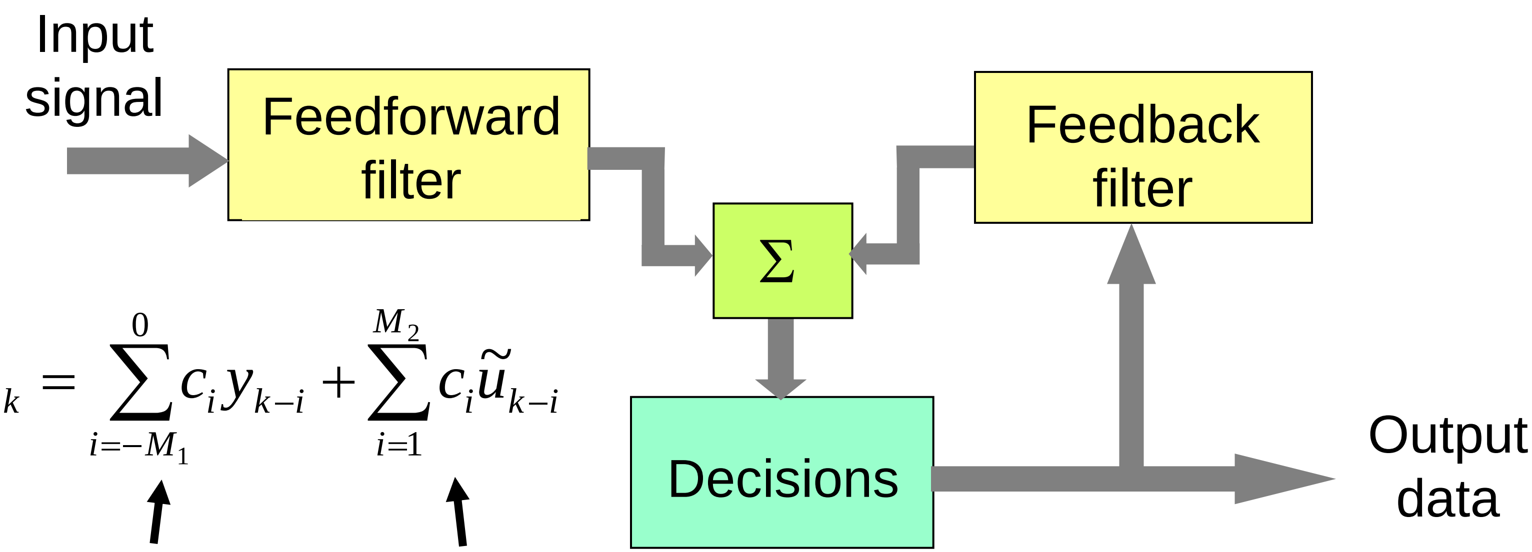
Least mean square iterative algorithm

Coefficients c updated with step size parameter μ
$c_{k+1} = c_k + \mu y_k e_k^*$. Simple, but still too slow for many applications. Need to look for other algorithms.



Non-linear equalisers, decision feedback

Two parts, feedforward and feedback filters. The feedback provides a noise-free version of received symbols used to remove ISI. If detection errors the result may be catastrophic with many further errors to come, error propagation phenomenon.



$$\hat{u}_k = \underbrace{\sum_{i=-M_1}^{0} c_i y_{k-i}}_{\text{Feedforward}} + \underbrace{\sum_{i=1}^{M_2} c_i \tilde{u}_{k-i}}_{\text{Feedback}}$$

Maximum likelihood sequence estimator

- Estimate data sequence which minimises mean squared error between TX and RX sequences:

$$D^2(\mathbf{b}) = E\left[\left|s(t) - u(t,\mathbf{b})\right|^2\right] = E\left[\left|s(t)\right|^2 + \left|u(t,\mathbf{b})\right|^2 - 2\,\mathrm{Re}\left(s(t)u^*(t,\mathbf{b})\right)\right]$$

- Equivalent to maximising this metric:

$$J(\mathbf{b}) = E\left[\mathrm{Re}\left(s(t)u^*(t,\mathbf{b})\right)\right]$$

- If statistics constant with time over *p* symbols:

$$J_p(\mathbf{b}) = \int_{t=0}^{pT} \mathrm{Re}\left(s(t)u^*(t,\mathbf{b})\right)dt$$

- Calculate over all possible sequences, maximum likelihood sequence estimation (MLSE)

Viterbi equalisation

- MLSE requires search over M^P possible sequences, where M is number of bits per symbol – too complex
- Rewrite metric as:

$$J_p(\mathbf{b}) = \int_{t=0}^{(p-1)T} \mathrm{Re}\left(s(t)u^*(t,\mathbf{b})\right)dt + \int_{t=(p-1)T}^{pT} \mathrm{Re}\left(s(t)u^*(t,\mathbf{b})\right)dt$$

$$= J_{p-1}(\mathbf{b}) + Z_p(\mathbf{b})$$

where $Z_p(\mathbf{b})$ is called the incremental metric.

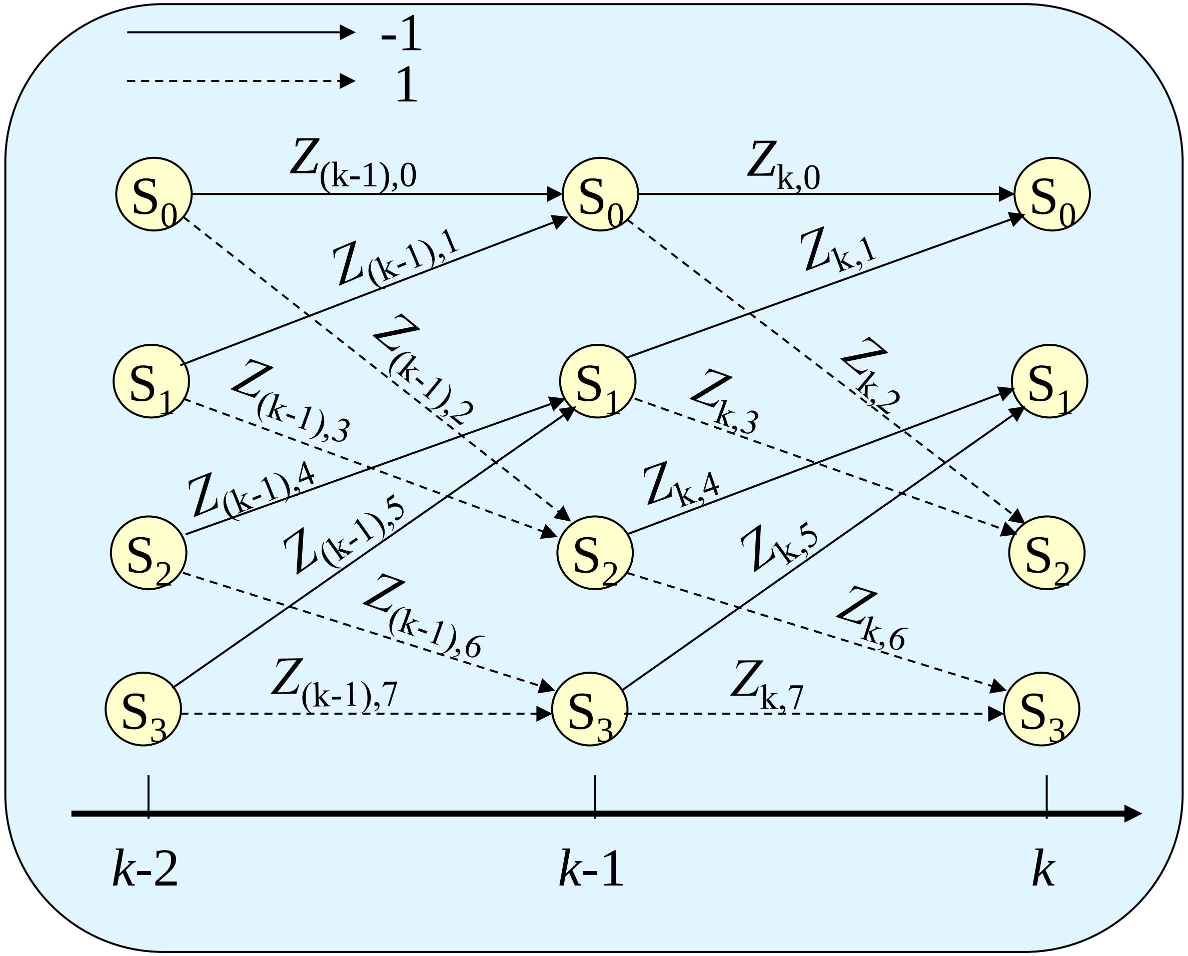
- This represents the correlation of the transmitted signal for sequence **b** with only the portion of the actual signal received during the p^{th} symbol interval.
- Example follows:

Viterbi equalisation state table and trellis diagram

Consider binary modulation (-1 or 1) and delay spread extending two intervals. ISI caused to bit depends on the values of the two previous bits. Four states possible for b_k.

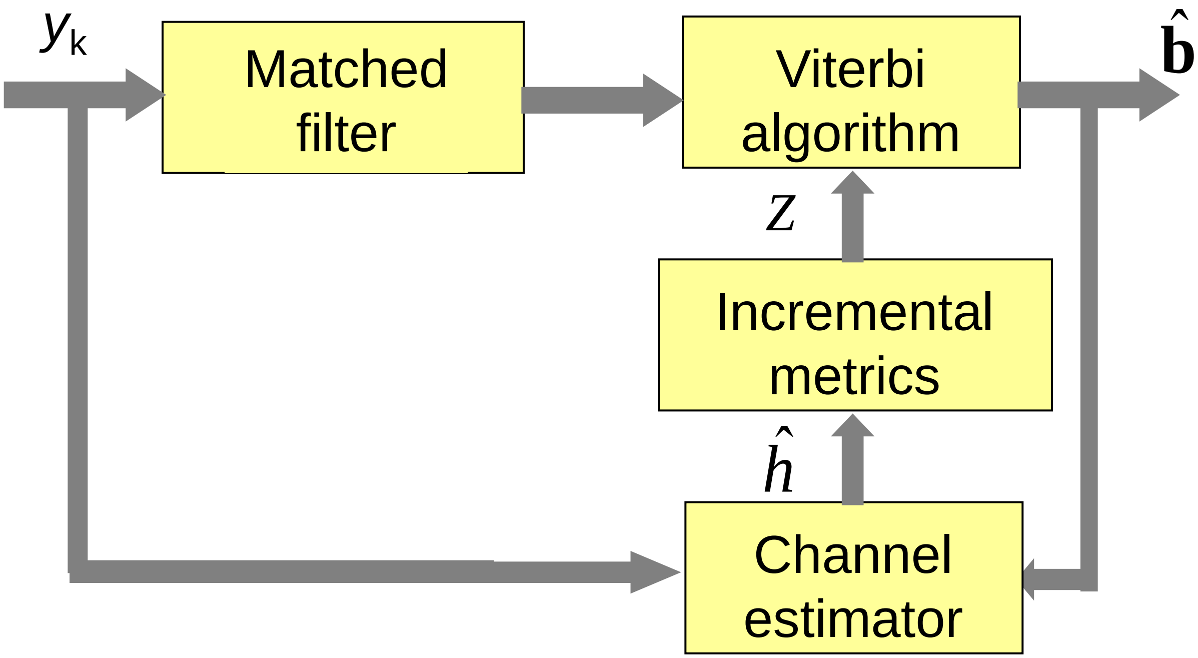
State	b_{k-2}	b_{k-1}
S_0	-1	-1
S_1	1	-1
S_2	-1	1
S_3	1	1

In the two intervals there are eight possible waveforms for $u(t)$ in the interval $[(k-1)T, kT]$.

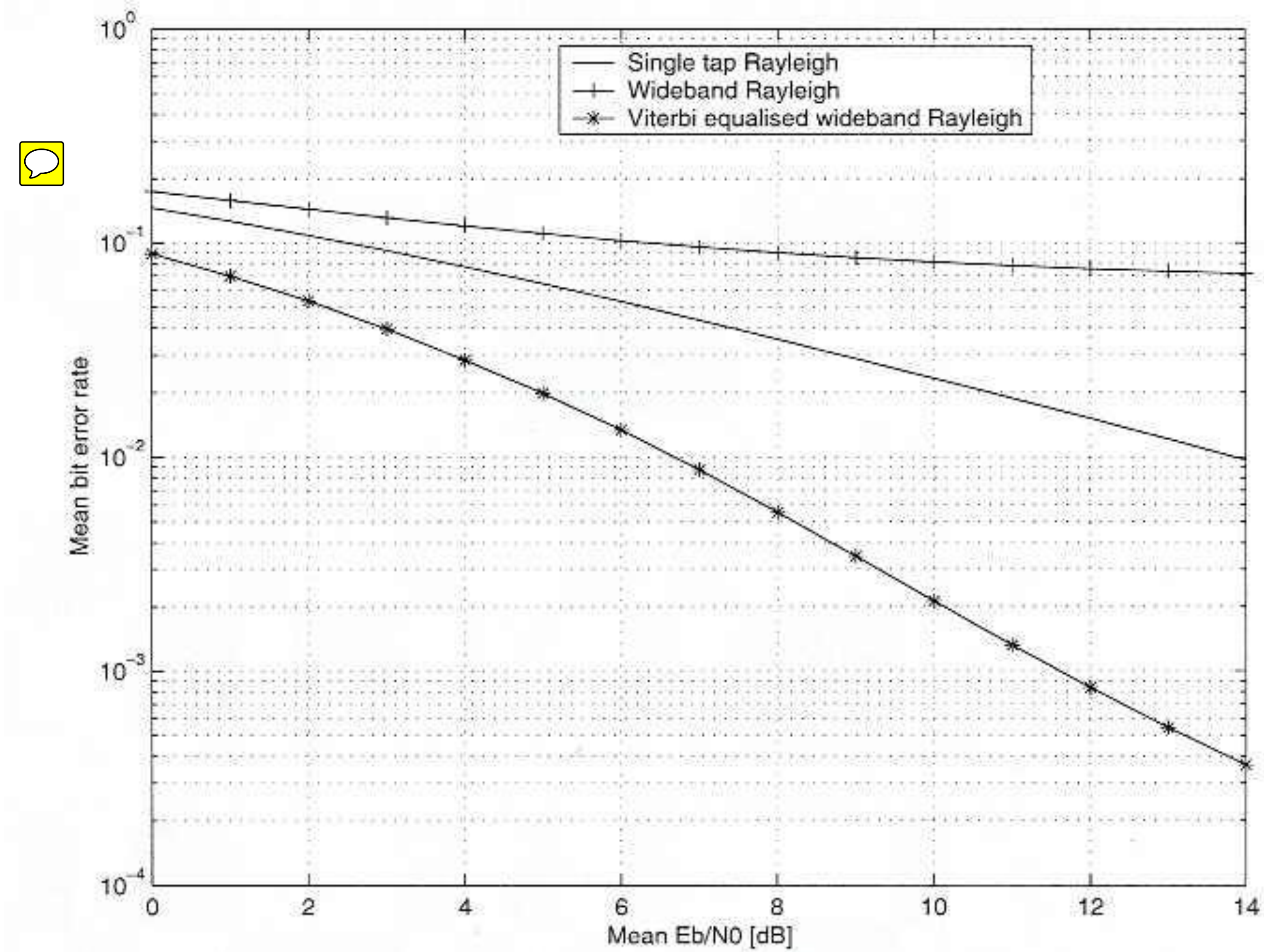


Largest total metric is the maximum likelihood sequence, know as Viterbi algorithm.

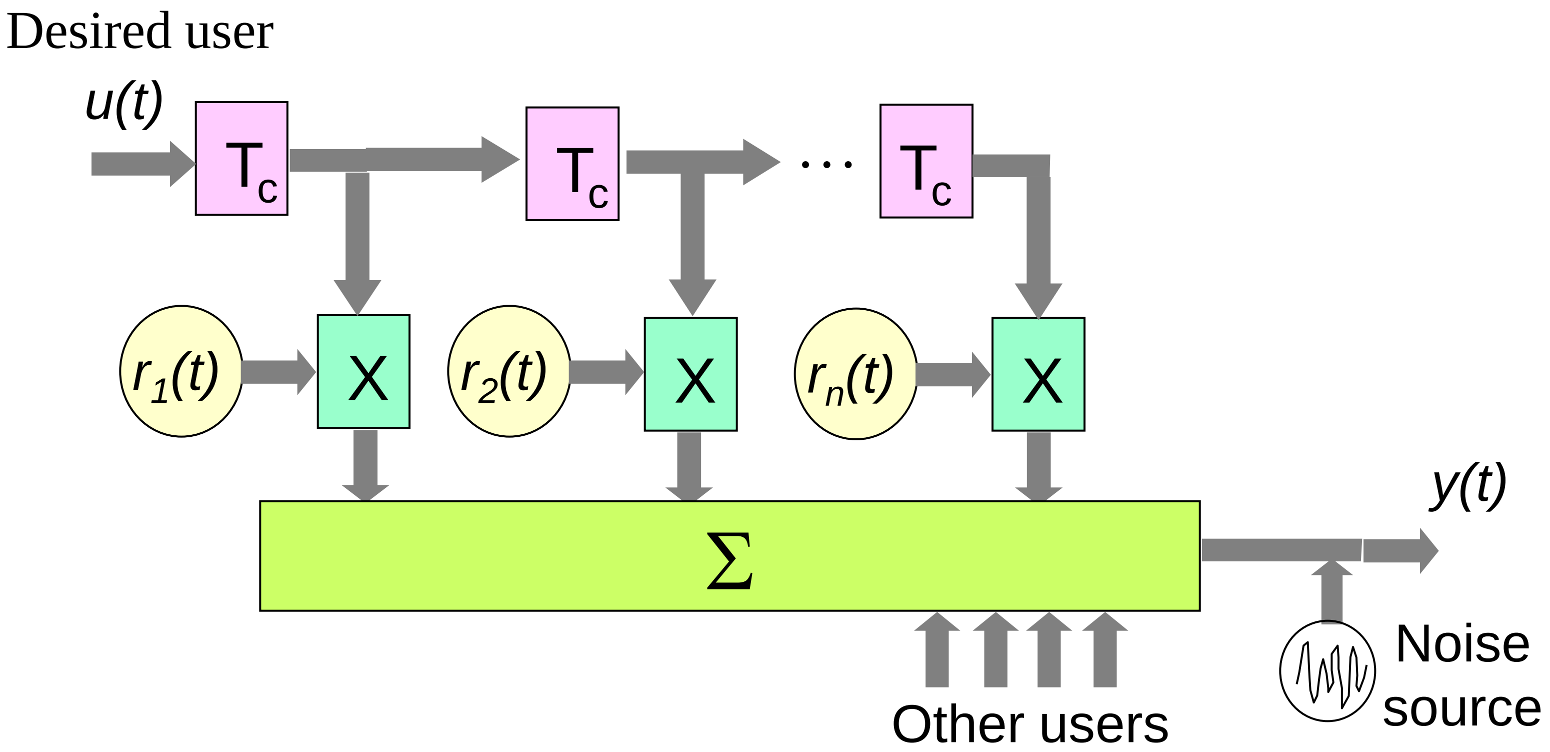
Viterbi equaliser structure



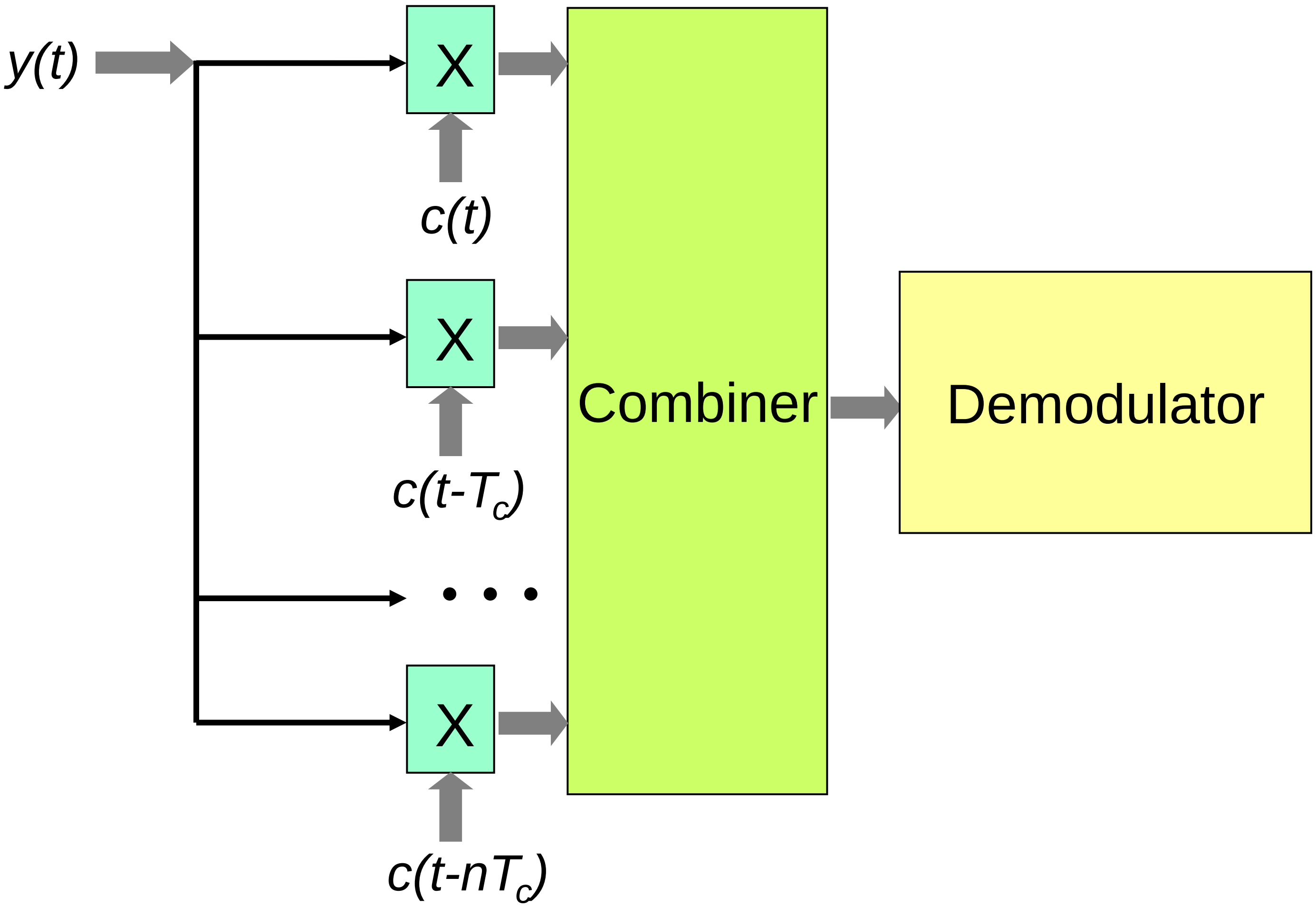
Viterbi equaliser performance for BPSK in a Rayleigh channel



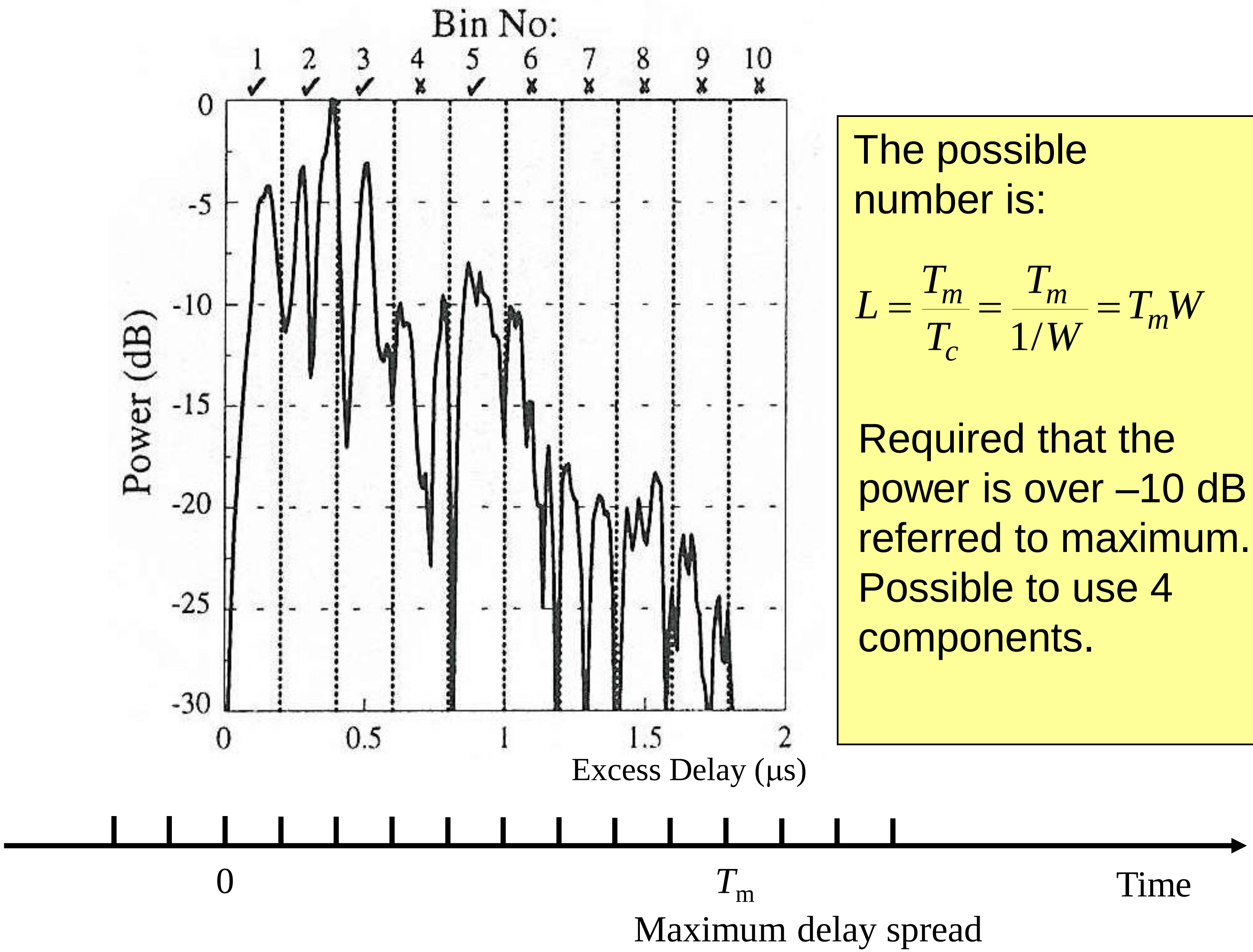
Wideband channel representation



Rake receiver



Possible use of multipath components



The possible number is:

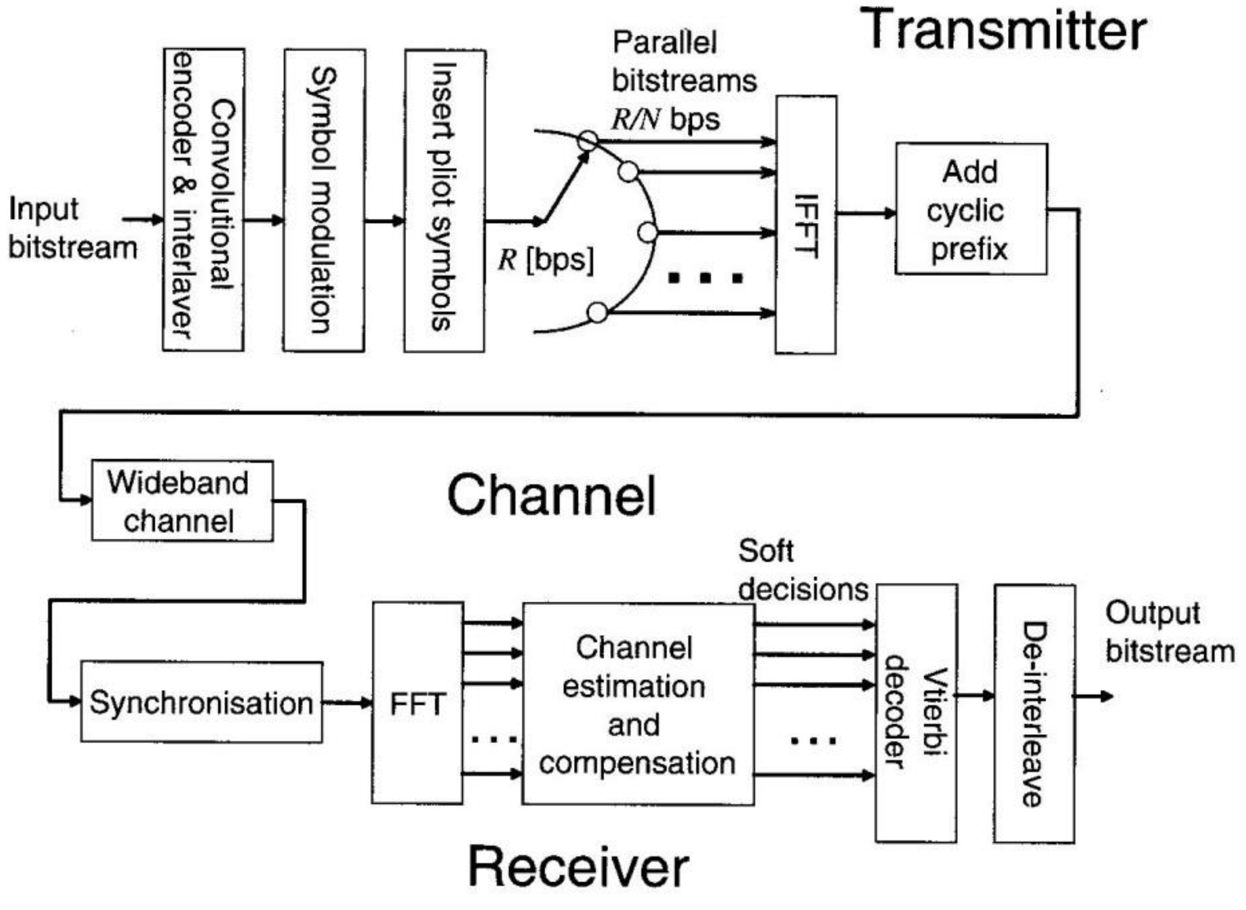
$$L = \frac{T_m}{T_c} = \frac{T_m}{1/W} = T_m W$$

Required that the power is over –10 dB referred to maximum. Possible to use 4 components.

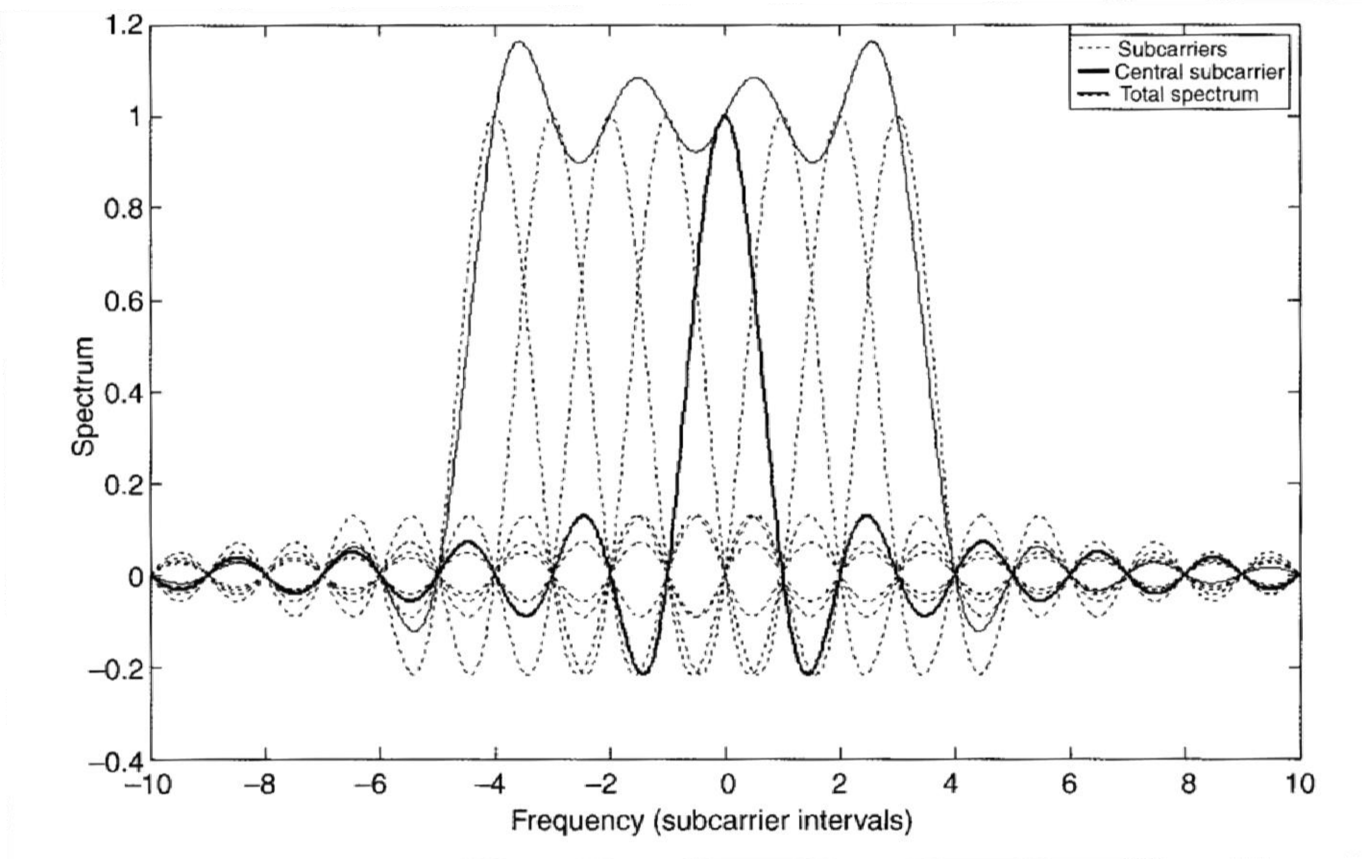
Orthogonal frequency division multiplexing (OFDM)

- Commonly used in several systems: DVB-T, DAB, WiMAX
- Subdivide a high bit stream *R* bit/s into *N* parallel streams each *R*/*N* bit/s, and modulate each sub-stream onto a sub-carrier
- Delay spread of N-times can be tolerated for each sub-stream compared to the single channel main stream option
- Need guard-band
- Doppler needs to be considered

Generic OFDM system



OFDM spectrum



Conclusions

- Wideband channel can be overcome
- Linear equalisers improve performance by suppressing ISI
- Nonlinear equalisers can improve performance by making constructive use of ISI
- All require estimation of channel (implicit or explicit)