

- 1895 – Marconi – telegraf
- 1933 – Armstrong – FM modulácia
- 1946 – Personal Correspondence System – 150MHz (120kHz/kanál)
Improved Mobile Telephone Service (mobilné
prepojenie s verejnou tel. sieťou)
- 1947 – koncept bunkového systému
- 1970 – Advanced Mobile Phone Service
(GSM, IS-136, IS-95)
- 1990 – Vývoj UMTS

Dizajn antény	Estimácia uhlu dopadu	Využitie linky
zisk šírka pásma efektivita veľkosť smerovosť	minimalizácia chyby rozlíšenie	pokrytie kvalita redukcia interferencie priestorova efektivita

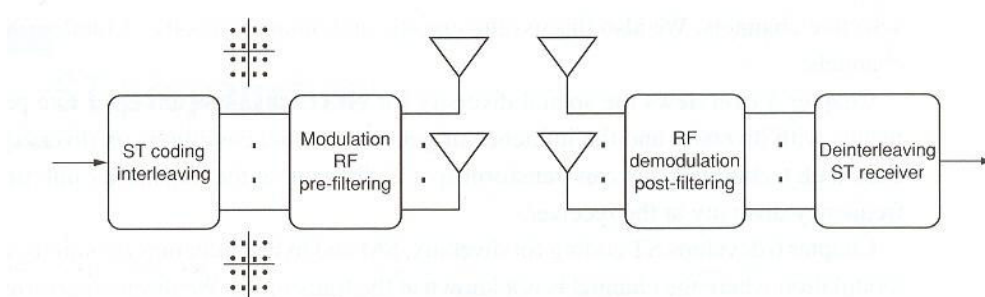
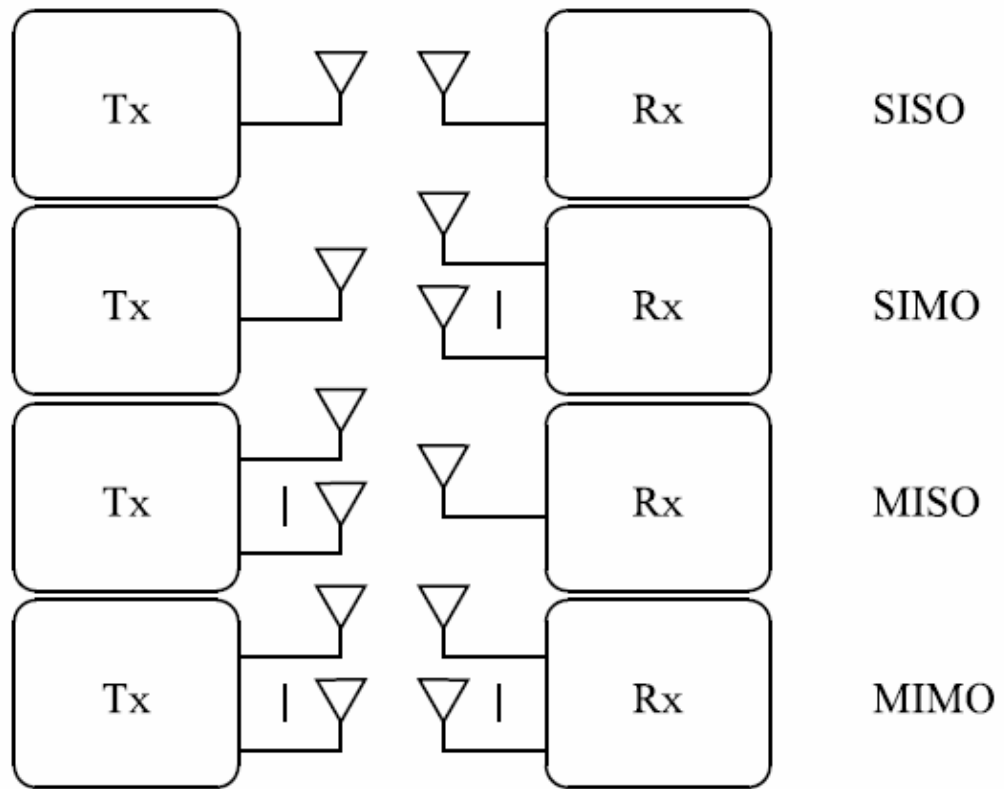


Figure 1.6: Schematic of a ST wireless communication system.

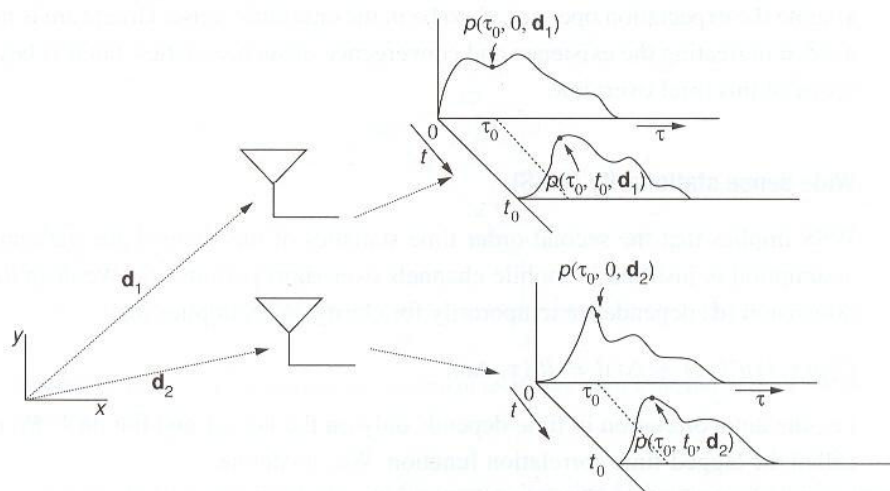


Figure 2.7: ST channel impulse response as a vector valued ST random field. Note that $p(\tau, t, \mathbf{d})$ is complex.

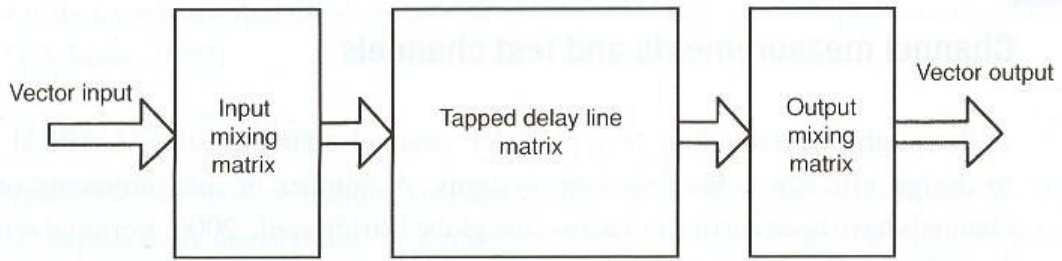
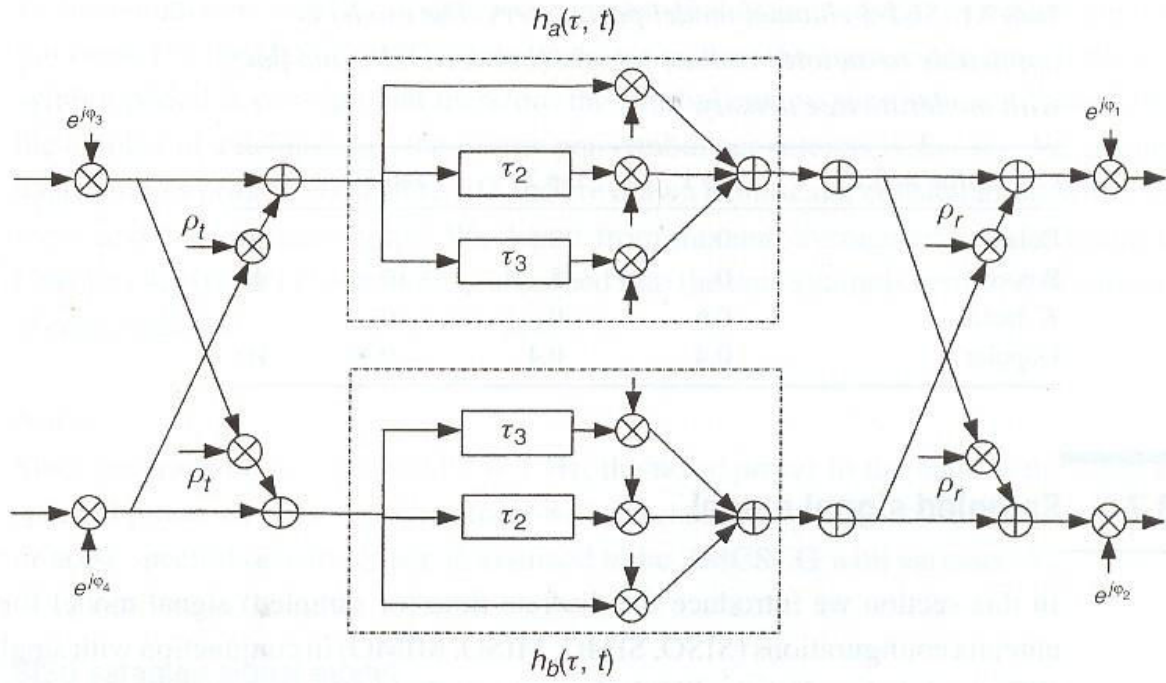


Figure 3.8: Schematic of a SUI channel.



$$\mathbf{H}(\tau, t) = \begin{bmatrix} e^{j\phi_3} & 0 \\ 0 & e^{j\phi_4} \end{bmatrix} \begin{bmatrix} 1 & \rho_t \\ \rho_t & 1 \end{bmatrix}^{1/2} \begin{bmatrix} h_{11}(\tau, t) & h_{12}(\tau, t) \\ h_{21}(\tau, t) & h_{22}(\tau, t) \end{bmatrix} \begin{bmatrix} 1 & \rho_r \\ \rho_r & 1 \end{bmatrix}^{1/2} \begin{bmatrix} e^{j\phi_1} & 0 \\ 0 & e^{j\phi_2} \end{bmatrix}$$

$$h_{ij}(\tau, t) = h_{ij}(0, t) \delta(\tau) + \sum_{l=1,2} h_{ij}(\tau_l, t) \delta(\tau - \tau_l)$$

Stanford University Interim (SUI) channel models

Terrain Type	SUI channels
hilly terrain	SUI-1, SUI-2
Intermediate	SUI-3, SUI-4
flat terrain	SUI-5, SUI-6

K-Factor: Low

Doppler	Low delay spread	Moderate delay spread	delay spread
Low	SUI-3		SUI-5
High		SUI-4	SUI-6

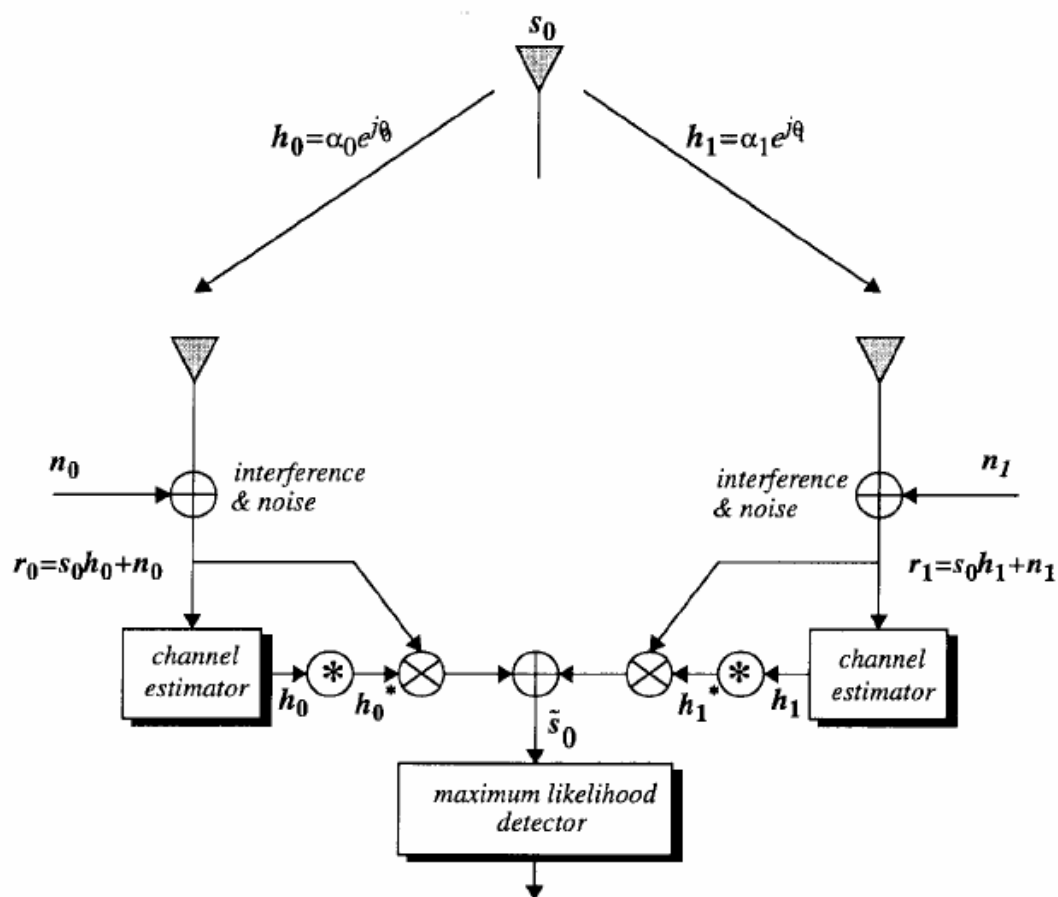
K-Factor: High

Doppler	Low delay spread	Moderate delay spread	delay spread
Low	SUI-1,2		
High			

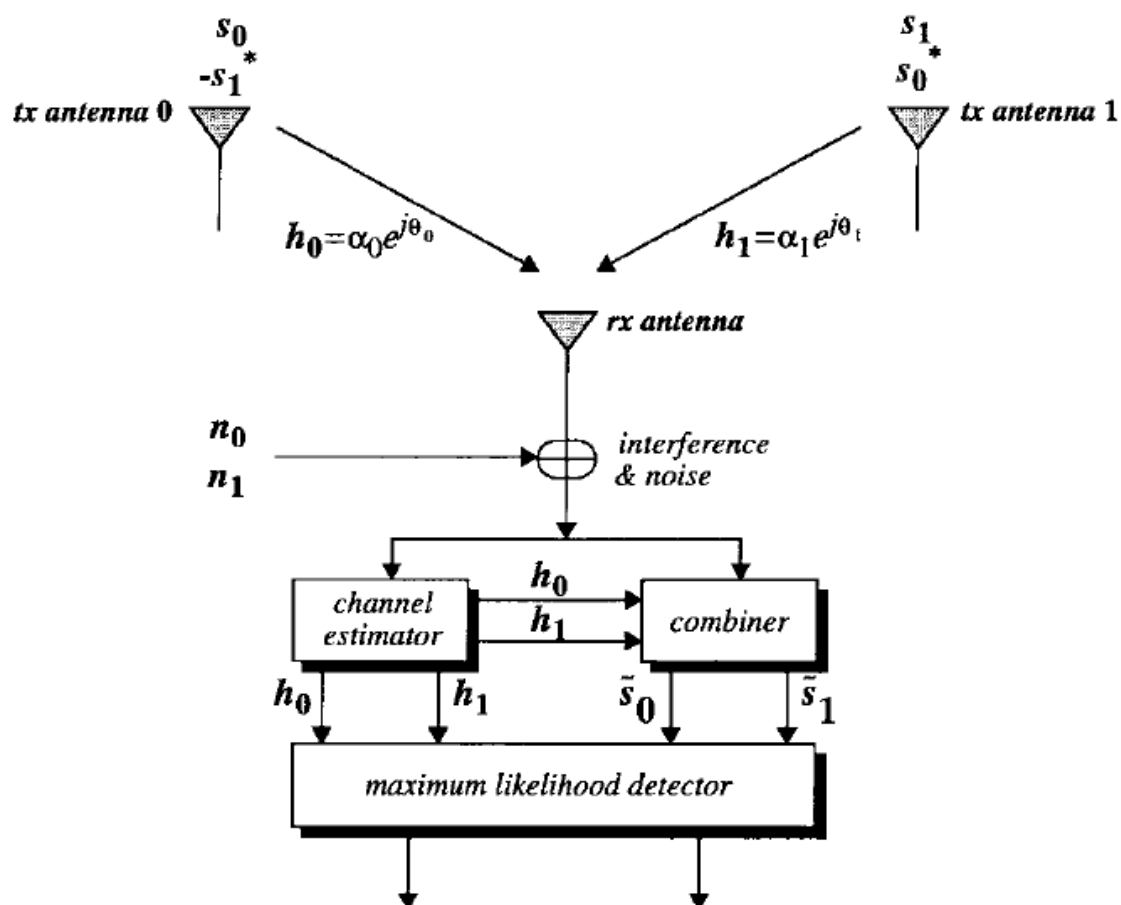
SUI – 3 Channel

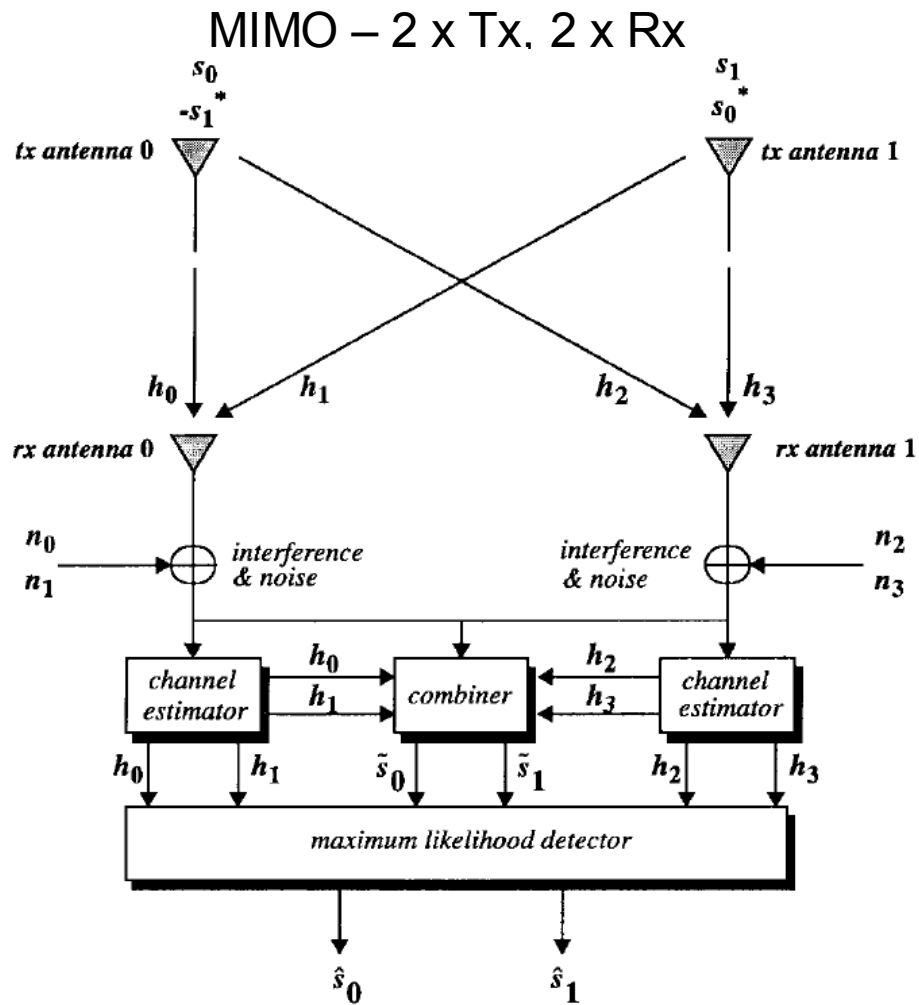
	Tap 1	Tap 2	Tap 3	Units
Delay	0	0.4	0.9	μ s
Power (omni ant.)	0	-5	-10	dB
90% K-fact. (omni)	1	0	0	
75% K-fact. (omni)	7	0	0	
Power (30° ant.)	0	-11	-22	dB
90% K-fact. (30°)	3	0	0	
75% K-fact. (30°)	19	0	0	
Doppler	0.4	0.3	0.5	Hz
Antenna Correlation: $\rho_{ENV} = 0.4$ Gain Reduction Factor: GRF = 3 dB Normalization Factor: $F_{omni} = -1.5113$ dB, $F_{30^\circ} = -0.3573$ dB				
Terrain Type: B Omni antenna: $\tau_{RMS} = 0.264$ μ s, overall K: K = 0.5 (90%); K = 1.6 (75%) 30° antenna: $\tau_{RMS} = 0.123$ μ s, overall K: K = 2.2 (90%); K = 7.0 (75%)				

Maximal-Ratio Receive Combining Scheme



MISO – 2 x Tx, 1 x Rx





THE ENCODING AND TRANSMISSION SEQUENCE FOR THE TWO-BRANCH TRANSMIT DIVERSITY SCHEME

	antenna 0	antenna 1
time t	s_0	s_1
time $t + T$	$-s_1^*$	s_0^*

THE DEFINITION OF CHANNELS BETWEEN THE TRANSMIT AND RECEIVE ANTENNAS

	rx antenna 0	rx antenna 1
tx antenna 0	h_0	h_2
tx antenna 1	h_1	h_3

THE NOTATION FOR THE RECEIVED SIGNALS AT THE TWO RECEIVE ANTENNAS

	rx antenna 0	rx antenna 1
time t	r_0	r_2
time $t + T$	r_1	r_3

Typy space-time kódov

- **MRRC** – tradičný spôsob kombinovania prijatých signálov z rôznych antén využívaný aj v GSM bazových stanicach.
- **Alamoutiho schéma (1998)** – najjednoduchšia s dvoma vysielacími a jednou alebo viacerými prijímacími anténami.
- **STBC (1998-99)** – blokové časovo-priestorové kódy. Kódovanie pomocou matice kódu. Dekódovanie je výberom symbolov, ktoré boli vyslané s najväčšou pravdepodobnosťou porovnaním s lineárnou kombináciou prijatých signálov v priestore a čase.
- **STTC (1998)** – Mriežkové časovo-priestorové kódy. Mapovanie vstupu do prechodov medzi stavmi v prechodovom diagrame. Princíp je podobný konvolučnému kódu, avšak jeden stav je definovaný cez viacero vysielacích antén. Dekódovanie je možné aj výberom najpravdepodobnejšej možnosti, alebo Viterbiho dekóderom.
- **Cayleyho kódy (2000)** – diferenčné časovo-priestorové kódy, nevyžadujú úplnú znalosť kanála na strane prijímača. Využíva Cayleyho transformáciu a špeciálne Hermitove matice, ktoré kód definujú.
- **BLAST** – „Bell Labs Layered Space-Time“, diagonálna BLAST schéma (D-BLAST), vertikálna BLAST schéma (V-BLAST). Kódovanie nie je potrebné, každá anténa vysieľa vlastné dáta, avšak dekóder je o to náročnejší. Využíva štatistické nulovanie signálov.
- ...

Space-Time Block codes

$$\begin{pmatrix} x_1 & x_2 \\ -x_2 & x_1 \end{pmatrix} \quad \begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2 & x_1 & -x_4 & x_3 \\ -x_3 & x_4 & x_1 & -x_2 \\ -x_4 & -x_3 & x_2 & x_1 \end{pmatrix}$$

$$\begin{bmatrix} x_1 & x_1 & x_1 \\ -x_2 & x_1 & -x_4 \\ -x_3 & x_4 & x_1 \\ -x_4 & -x_3 & x_2 \end{bmatrix} \quad \begin{bmatrix} x_1 & x_2 & x_3 & x_4 & x_5 \\ -x_2 & x_1 & x_4 & -x_3 & x_6 \\ -x_3 & -x_4 & x_1 & x_2 & x_7 \\ -x_4 & -x_3 & -x_2 & x_1 & x_8 \\ -x_5 & -x_6 & -x_7 & -x_8 & x_1 \\ -x_6 & x_5 & -x_8 & -x_7 & -x_2 \\ -x_7 & x_8 & x_5 & -x_6 & -x_3 \\ -x_8 & -x_7 & x_6 & x_5 & -x_4 \end{bmatrix}$$

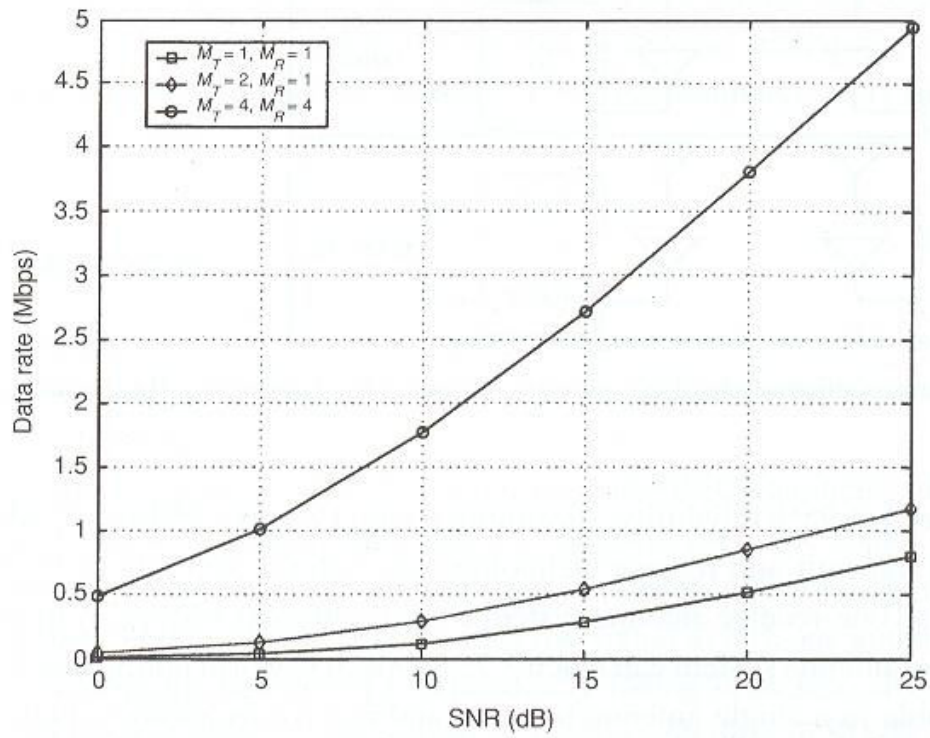


Figure 1.4: Data rate (at 95% reliability) vs SNR for different antenna configurations. Channel bandwidth is 200 KHz.

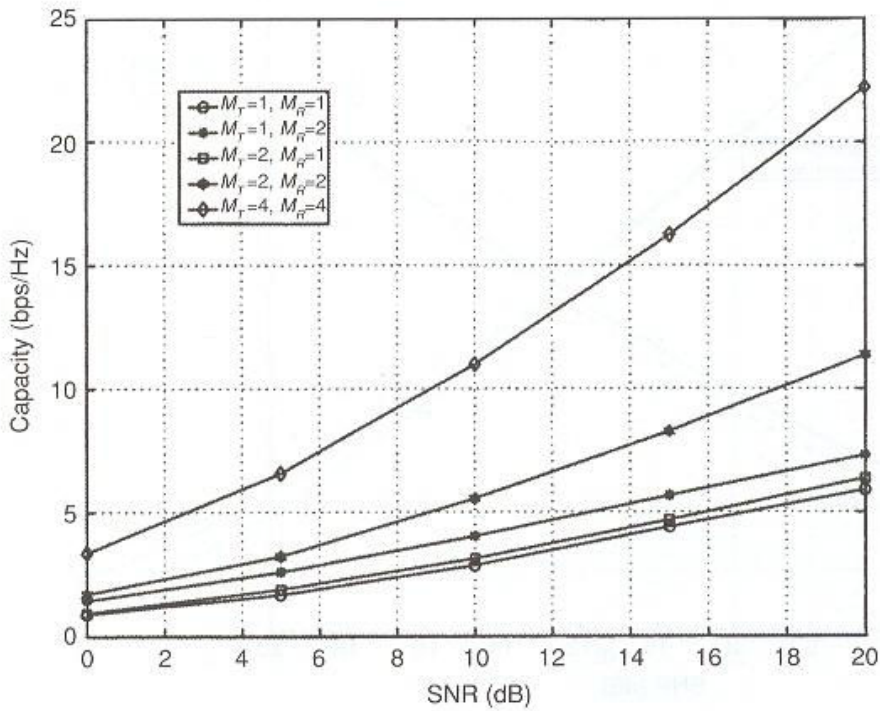
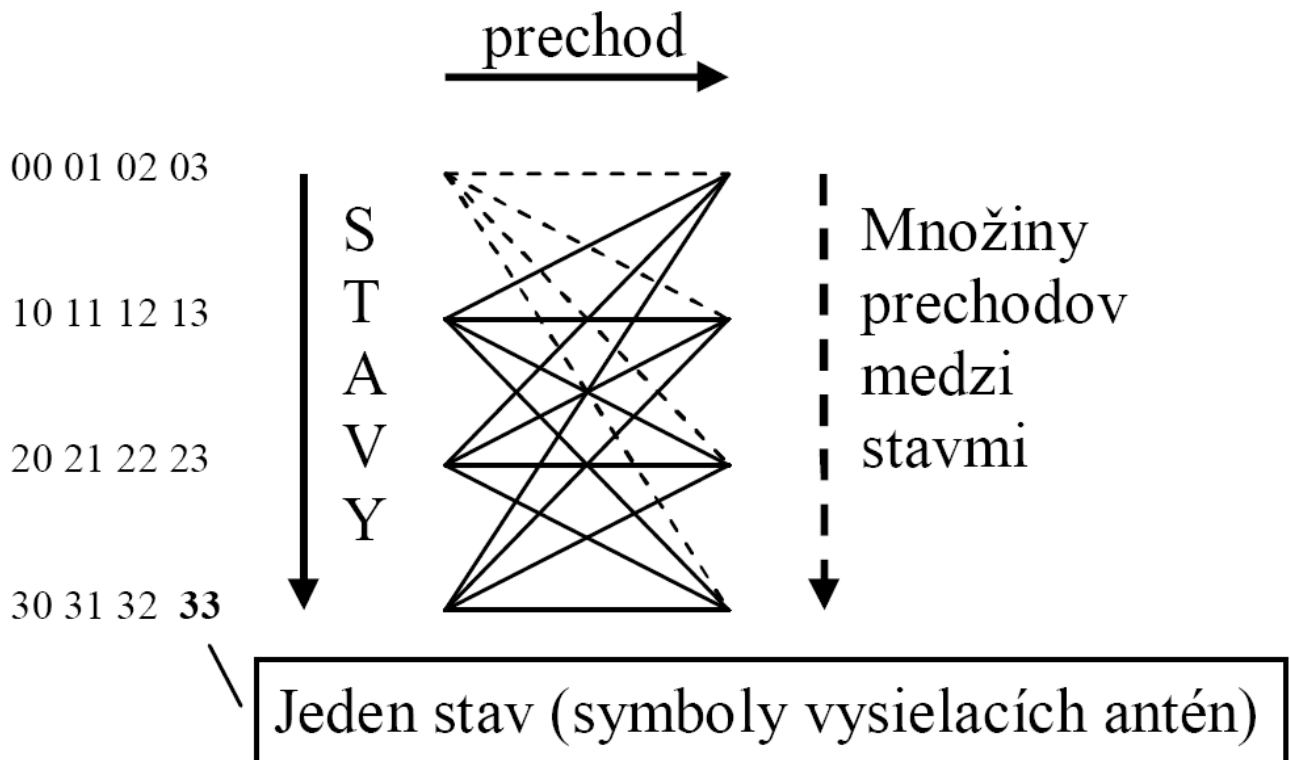
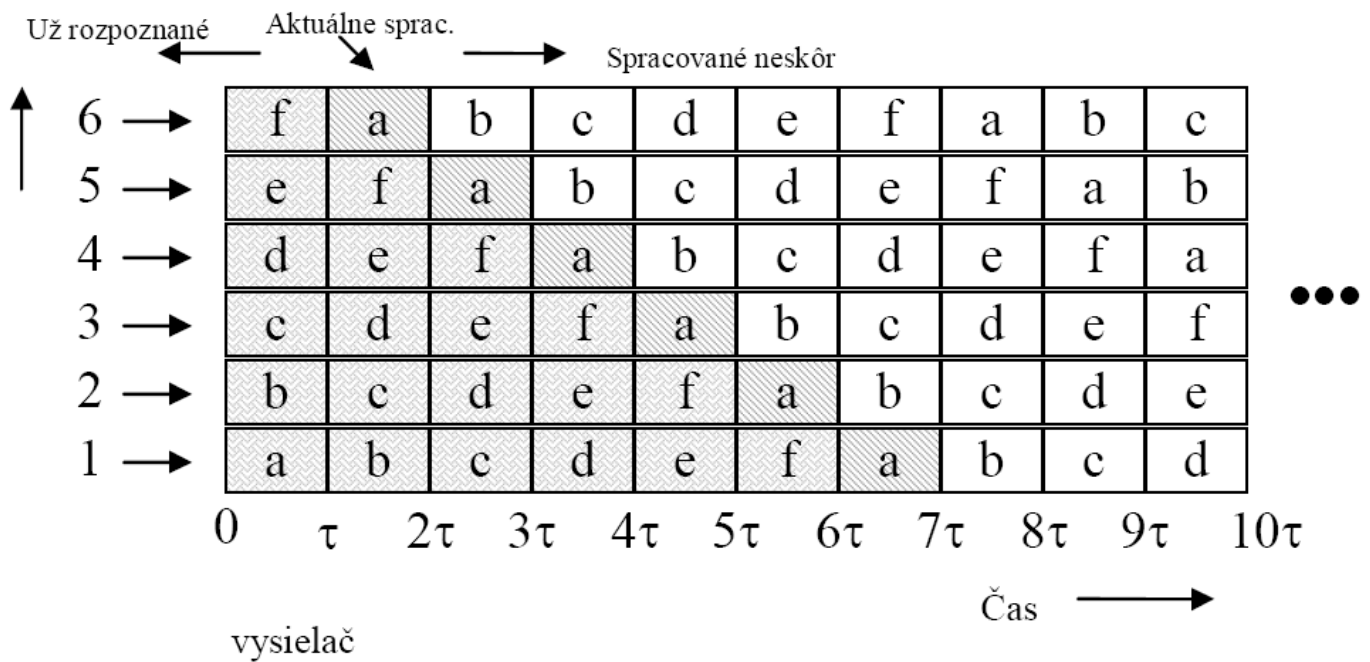


Figure 4.5: Ergodic capacity for different antenna configurations. Note that the SIMO channel has a higher ergodic capacity than the MISO channel.

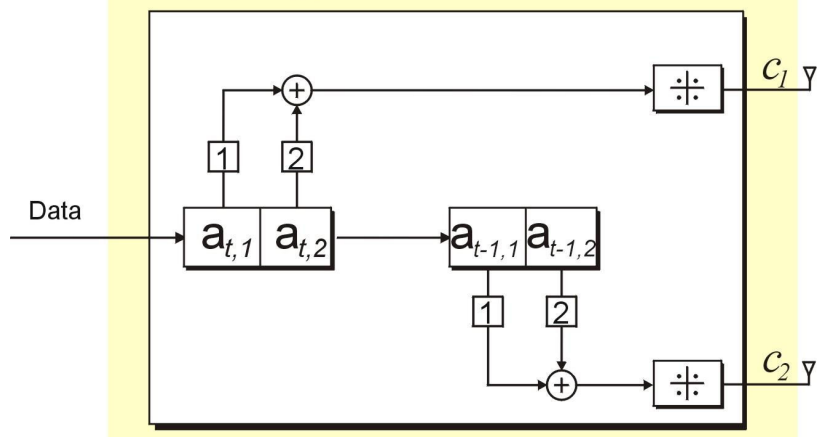
Space-Time Trellis Codes



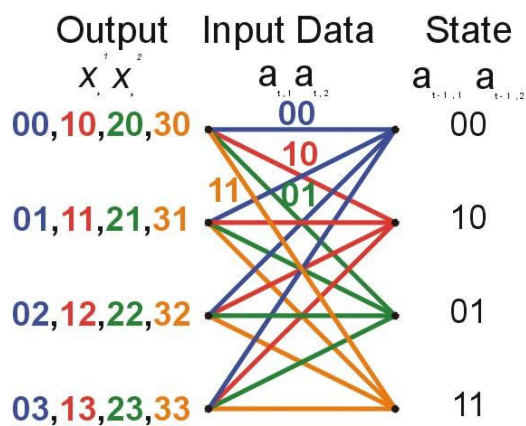
D-BLAST



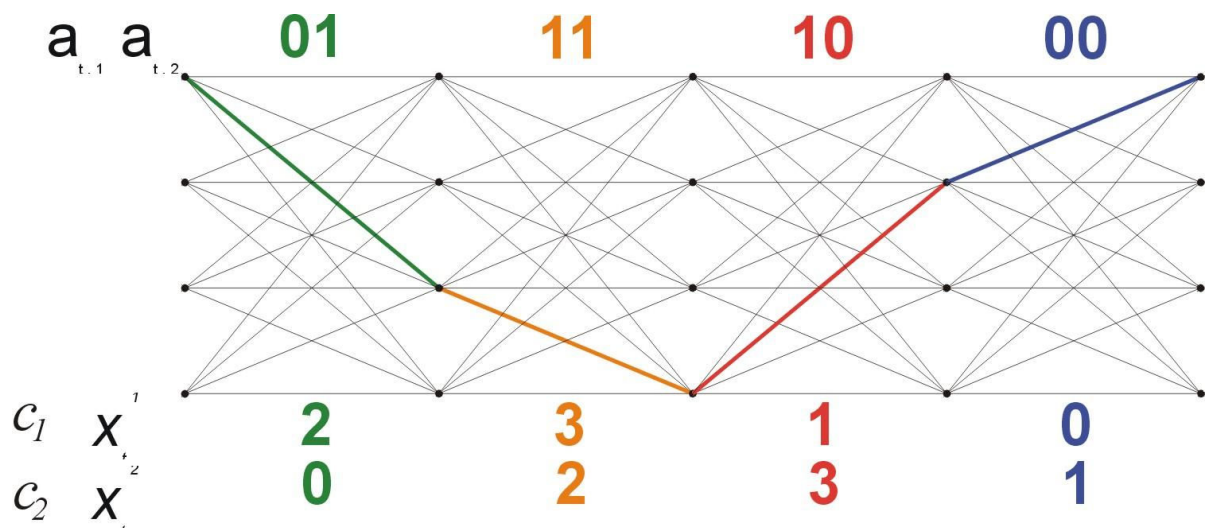
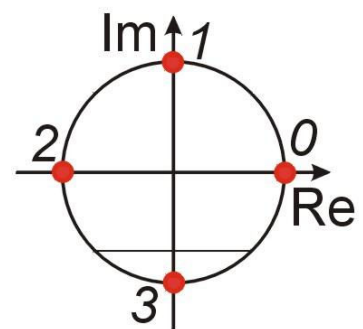
Transmitter



Trellis

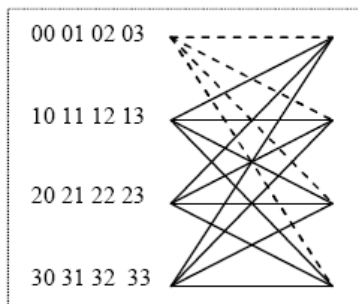


QPSK Constellation

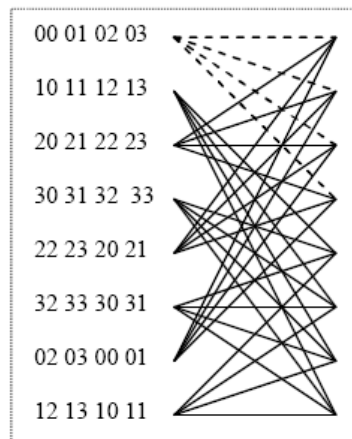


$$\begin{pmatrix} 2 & 3 & 1 & 0 \\ 0 & 2 & 3 & 1 \end{pmatrix}$$

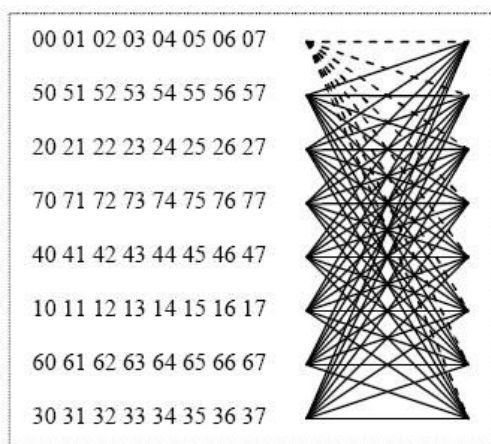
$$\begin{pmatrix} -1 & -j & j & 1 \\ 1 & -1 & -j & j \end{pmatrix}$$



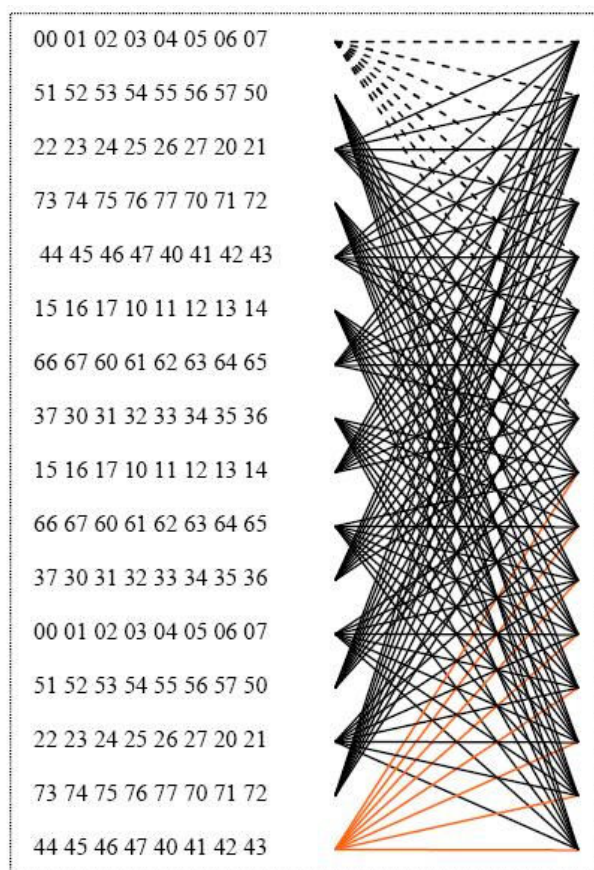
**Obr. 33: 2-ST kód, 4-PSK,
4 stavý, 2 b/s/Hz**



**Obr. 34: 2-ST kód, 4-PSK,
8 stavov, 2 b/s/Hz**



**Obr. 35: 2-ST kód, 8-PSK,
8 stavov, 3 b/s/Hz**



**Obr. 36: 2-ST kód, 8-PSK,
16 stavov, 3 b/s/Hz**