



Isfahan University
of Technology

In the name of GOD

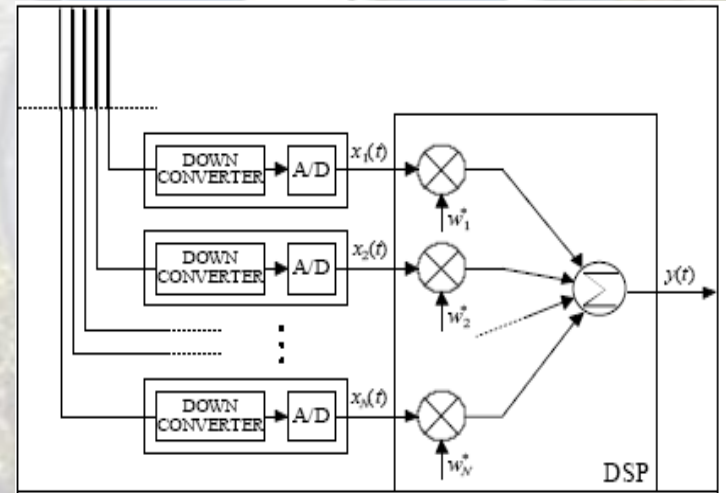
*Spatial and Temporal Communication
Theory Using Adaptive Antenna Array*

Instructor: Professor M. J. Omid
tayebeh gholipur
summer 2009

introduction

An adaptive antenna array is named a **software antenna** because it can form a desired antenna pattern and adaptively control it if an appropriate set of antenna weights is provided and updated software

typical software antenna is a digital beamformer which is implemented by the combination of a phased array, downconverter, A/D converter, and field programable arrays or digital signal processors



introduction

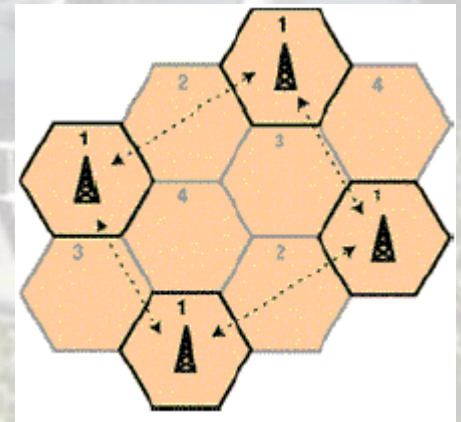
Based on the signal processing technique followed at the baseband output of the antenna array smart antennas can be grouped into four basic types:

- 1- Beamforming
- 2- Diversity combining
- 3- Space time equalization
- 4- Multiple input multiple output (MIMO) processing

An *adaptive antenna array* can be considered an **adaptive filter** in space and time domains for radio communications

Spatial and Temporal Communication

- ▶ spatial and temporal communication theory based on an adaptive antenna array ,such as temporal and spatial channel modeling ,equalization,..
- ▶ recent research interests in the field of wireless communications for higher quality and variable speed of transmission for multimedia information
- ▶ Signal distortion is one of the main problems of wireless personal communications. It can be classified as **intersymbol interference** (ISI) due to the signal delay of going through the multipath channel, and **co-channel interference** (CCI) due to the multiple access



Equalization

- when the **delay time** is long, the complexity of the equalization system increases.
- An antenna array can reduce the interference according to the arrival angles or directions of arrival (DOA).
- Even if the **delay time** is large, the system complexity does not increase because the antenna array can reduce the interference by using the antenna directivity.

Spatial and Temporal Communication

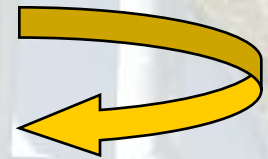
This concept has been also successfully used for a long time in many engineering applications such as **radar** and aerospace **technology** Adaptive

An **adaptive antenna array** continuously adjusts its own pattern by means of feedback control

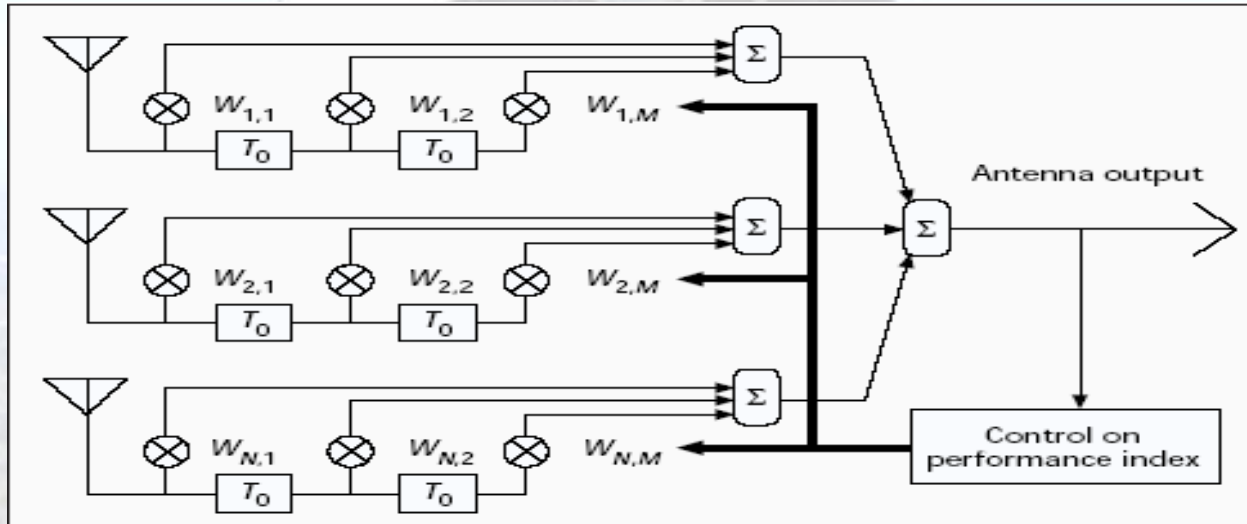
by adjusting the **amplitude** and **phase** of the signal from each element before combining the signals



The pattern of an array is easily controlled



Spatial and Temporal Communication



■ **Figure 1.** An adaptive TDL antenna array with N element antenna and M taps in each element.

$$y(t) = \sum_{n=1}^N \sum_{m=1}^M x(t - mT_0) w_{n,m} \exp(-j \varphi) \quad \varphi = \frac{2\pi S \sin \theta}{\lambda},$$

λ : wavelength of an incoming signal,

S : the distance between adjacent elements

θ : the DOA of the received signal

φ : phase different between the received signal at elements

Spatial and Temporal Communication

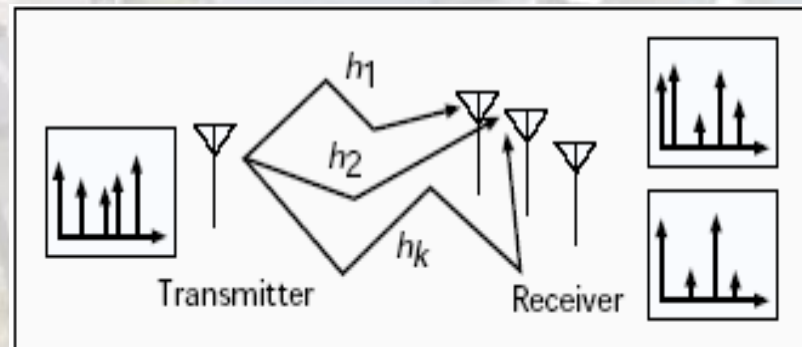
The antenna transfer **function** in both spatial frequency and temporal frequency domain, $f = \omega/2\pi$ is given by:

$$H(\omega, \theta) = \sum_{m=1}^M \exp(-jm\omega T_0) \sum_{n=1}^N \omega_{n,m} \exp(-jn\varphi)$$

This equation represents the antenna pattern when ω is a constant, while it represents the frequency response when θ is a constant. Therefore, the adaptive TDL antenna array can be employed as a tool for signaling, **equalization** and detection in space and time domains

Spatial and Temporal Channel Model

- ▶ In order to design and analyze an antenna array, a radio transmission **model** should be modeled in both the space and time domains .
- ▶ A multipath fading channel, such as a mobile radio channel, is modeled in which a transmitted signal from one signal source arrives at the receiver with different **angles and delays**.
- ▶ The received signal is defined by its delay profile or impulse response for a particular DOA of the received signal .



■ **Figure 2.** *Spatial and temporal multipath channel model (2D channel model with paths defined by DOAs and time impulse responses of the paths).*

Spatial and Temporal Channel Model

Therefore, the **impulse response** of the k th path $h_k(t)$ with DOA θ_k , ($k = 1, 2, \dots, K$) is represented by

$$h_k(t) = \sum_{i=1}^{I_k} g_{k,i} \delta(t - \tau_{k,i}) \exp(j\psi_{k,i})$$

where, $g_{k,i}$, $\tau_{k,i}$ and $\psi_{k,i}$ denote path amplitude, path delay, and path phase of the i th delayed signal through the k th path.

An equivalent complex baseband representation of the received signal $R_n(t, \theta_k)$, in the n th antenna element is where $S_b(t)$ is the complex baseband transmitted signal and $\phi_{k,i}$ is the net phase offset

$$R_n(t, \theta_k) = \sum_{i=1}^{I_k} g_{k,i} S_b(t - \tau_{k,i}) \times \exp(-g 2\pi S \frac{\sin \theta_k}{\lambda}) \exp(j\phi_{k,i})$$

Spatial and Temporal Equalization

By using the above-mentioned spatial and temporal channel model, we can derive an extended Nyquist theorem for a known channel. Moreover, for unknown or time varying channels, various algorithms for updating antenna weights are discussed

Spatial and Temporal Nyquist Criterion

The array output $y(t)$ can be replaced by $y(t, \Theta)$ because the array output depends on time t and arrival angle set $\Theta = (\theta_1, \theta_2, \dots, \theta_k)$
array output :

$$y(t, \Theta) = \sum_{k=1}^K p(t, \theta_k)$$

Spatial and Temporal Communication

where $p(t, \theta_k)$ is defined as

$$p(t, \theta_k) = \sum_{n=1}^N \sum_{m=1}^M \sum_{i=1}^{I_k} \omega_{n,m} g_{k,i} \exp(j\phi_{k,i}) \exp(-j2\pi S \frac{\sin \theta_k}{\lambda}) S_b(t - \tau_{k,i} - mT_0)$$

Suppose that θ_l represents the desired arrival angle. If $p(t, \theta)$ equals the symbol s_l at $t = lT_d$ and $\theta = \theta_l$, and equals zero elsewhere, ISI must be zero. This condition is named the generalized Nyquist criterion in both space and time domains. Then the criterion is represented by

$$p(lT_d, \theta) = s_l \delta'(t - lT_d, \theta - \theta_l)$$

Adaptive Spatial and Time Equalization for Reducing ISI

- Several criteria for spatial and temporal equalization such as ZF (zero forcing) and MMSE (minimum mean square error) are available to update the weights and tap coefficients. The ZF criterion satisfies the generalized Nyquist criterion in the noise-free case if there are an infinite number of taps and elements.
- If the permissible equalization error is given, there may be several combinations of taps and elements which achieve the same equalization error. Therefore, the number of antenna elements can be reduced by increasing the number of taps in some cases.

schemes to obtain the optimal weights are classified into these two groups

1-adaptive algorithms for deriving optimal antenna weights in the **time domain**

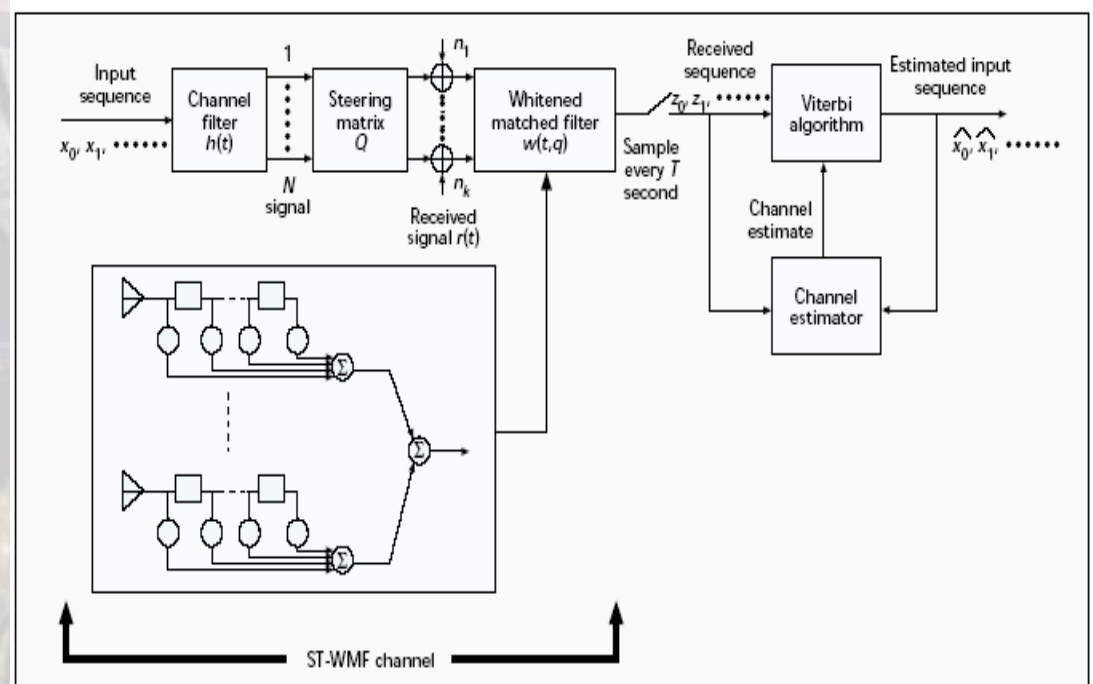
LMS , RLS , CMA

2-there is also research based on **DOA estimation** from the viewpoint of spectral analysis in the space domain, such as discrete Fourier transform (DFT) maximum entropy method (MEM) , MUSIC, and ESPRIT

Spatial and Temporal Optimum Receive

► Therefore, if the *processing speed* is fast enough to track time variation of channels, second algorithms can be more attractive for a fast fading channel than the temporal updating algorithm

In the previous section, spatial and temporal equalization whose purpose is to reduce ISI due to multipath in a channel was discussed



Spatial and Temporal Whitened Matched Filter

First, the spatially and temporally whitened matched filter (ST-WMF) is derived using a TDL antenna array . The SNR at the TDL antenna array output is represented using the delay operator D as

$$SNR = \frac{\sigma_s^2 \left| w^T (D, \Theta) \sum_{k=1}^K h_k (D) q(\theta_k) \right|^2}{\sigma^2 |w(D, \Theta)|^2}$$

$h_k(D)$, $w(D, \Theta)$, $q(\theta_k)$, σ_s^2 and σ^2 denote the impulse response of the k th path, the N -dimensional impulse response or weight vector of the array at the arrival angle set Θ , the steering vector for DOA θ_k of the k th path , the variance of the input sequence $x(D)$, and the noise power

Spatial and Temporal Whitened Matched Filter

From **Schwarz's inequality**, the optimal weight vector $W(D, \Theta)$ (N -dimensional) for maximizing the SNR at the TDL antenna array output is given by the time inversion $h_k(D^{-1})D^{K_0}$ ($k = 1, 2, \dots, K$) of the impulse response and the directivity information Θ as

$$w(D, \Theta) = \sum_{k=1}^K h_k(D^{-1})D^{K_0} q(\theta_k)$$
$$q(\theta_k) = \left[e^{-j\pi \sin \theta_k} \dots e^{-j(N-1)\pi \sin \theta_k} \right]$$

where K_0 satisfies $\max_{k=1,2,\dots,K} \{I_k\} \leq K_0$ for the delay spread of the path I_k

Spatial and Temporal Optimum Receiver

- Each antenna element receives signals.
- The received signals in each antenna element are filtered by an ST-WMF, which is matched to the transmission channel impulse response.
- The maximum likelihood sequence is estimated from the ST-WMF output.

probability $P(e)$ $P(e) \leq \alpha Q_{error}(d_{\min} / 2\sigma)$

where d_{\min} is the minimum Euclidean distance, α is a small constant, and Q_{error} is the error function.

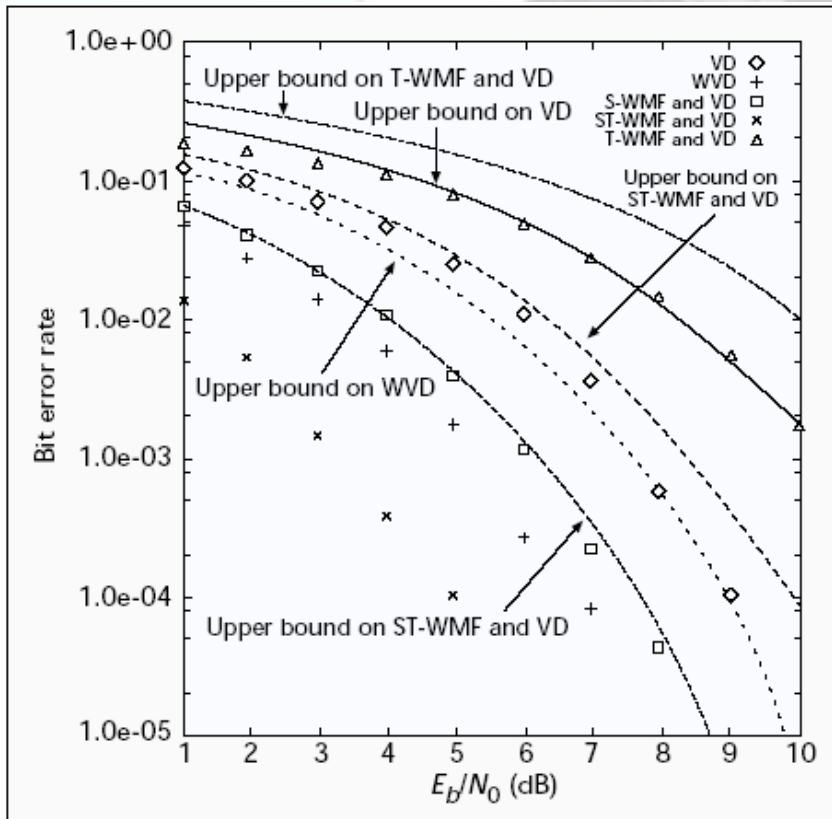
Spatial and Temporal Optimum Receiver

Since ISI is taken into account, the transmission rate R_{st} is derived as

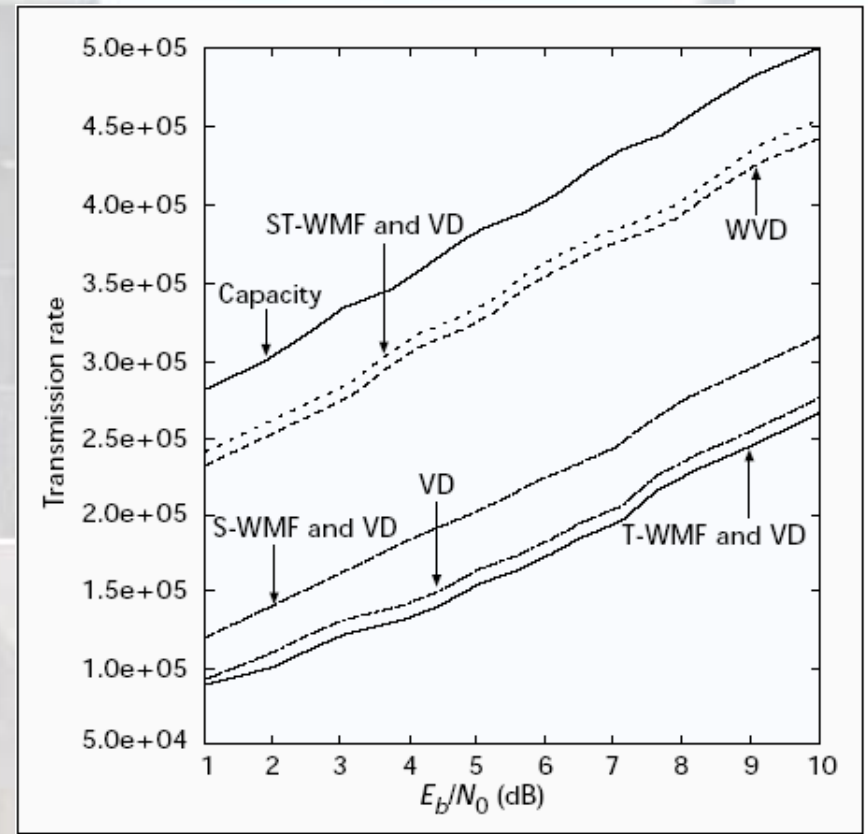
$$R_{st} = W \log \frac{\sigma_s^2 \sum_{k=0}^{2K-1} |g_k|^2 + \sigma^2}{\sigma^2}$$

where W and g_k is the signal bandwidth and the delay part of the discrete channel impulse response of the k th path, respectively.

SIMULATION



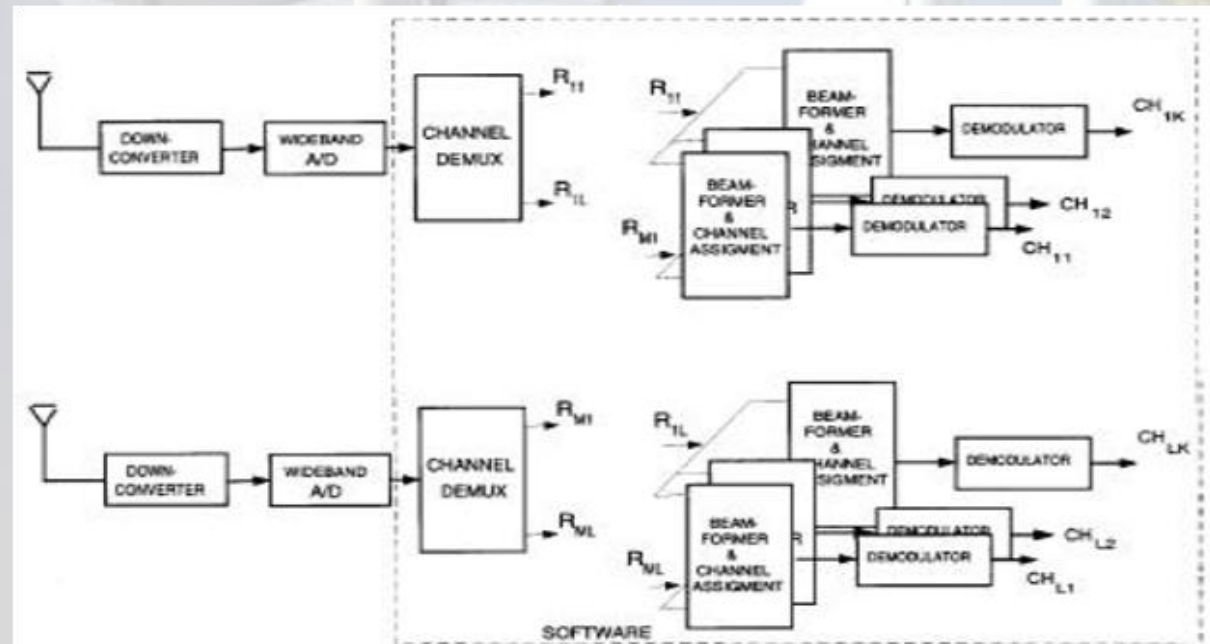
BER of optimum receivers in spatial and/or temporal domains.



Achievable transmission rate of optimum receivers comparing with Shannon capacity.

INTEGRATED SDR AND DIGITAL BEAMFORMING

Each antenna element has its own downconverter and ADC, but the subsequent beamforming and demodulation are implemented in software and are shared among all of the elements.



conclusion

- ▶ The addition of smart antennas to SDR base stations will require an **increase in computational** power, although this will depend on the nature of the beamforming and the system objectives of the antenna
- ▶ The digital hardware could be a combination of ASICs and DSPs : digital receiver may be realized by ASIC , and digital beamformer may be realized by software implemented in a DSP
- ▶ for example *Xilinx Virtex-E FPGAs on a BenADIC 20-channel , 14-bit data acquisition card* The card produces 3.675 gigabytes of digitized data every second



reference

1-Spatial and Temporal Communication Theor

Using Adaptive Antenna Array

Ryuji Kohno, Yokohama National University

2-How to Make Smart Antenna Arrays

by Malachy Devlin, Ph.D.

Chief Technology Officer

Nallatech m.devlin@nallatech.com

3- ANALYSIS OF SDMA & SMART ANTENNA TECHNIQUES FOR
EXISTING AND NEW MOBILE COMMUNICATION SYSTEMS Dukia L.

Miroslav(1)Jankovia Lj. Milan(2) Odadzia Lj. Borislav(2)

(1)Faculty of Electrical Engineering, Bul. Revolucije 73, 11000 Belgrade

(2)Community of Yugoslav PTT, Palmotiaeva 2, 11000 Belgrade



THE END