# MTUCI'S RESEARCH INTO ALGORITHMS OF SIGNALS PROCESSING FOR 5G & BEYOND

**Moscow Technical University of Communications and Informatics (MTUCI)**

Authors:
V.B.Kreyndelin,
T.B.K. Ben Rejeb,
A.E. Smirnov

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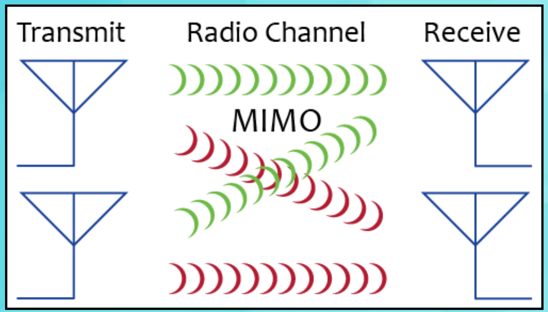
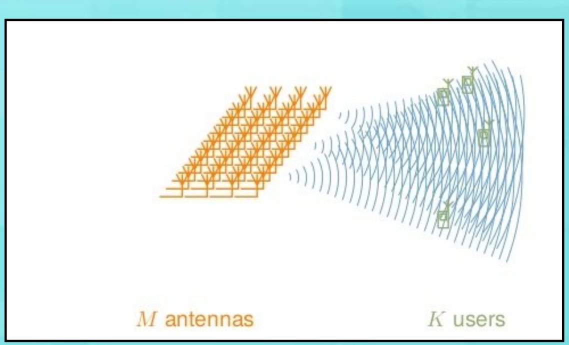
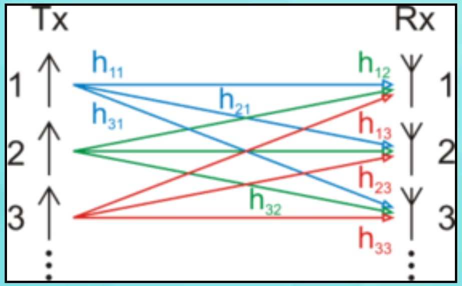
# 1. KEY ASPECTS OF CIVIL 5G WIRELESS COMMUNICATION SYSTEMS

- **I. Precoding techniques for MIMO systems**
- **II. Feedback techniques for MIMO systems**
- **III. Decreasing of computational complexity of demodulation algorithms**
- **IV. Development of demodulation techniques for massive MIMO systems**
- **V. New space-time codes (STC)**
- **VI. Antenna selection in MIMO systems**
- **VII. MIMO detection**



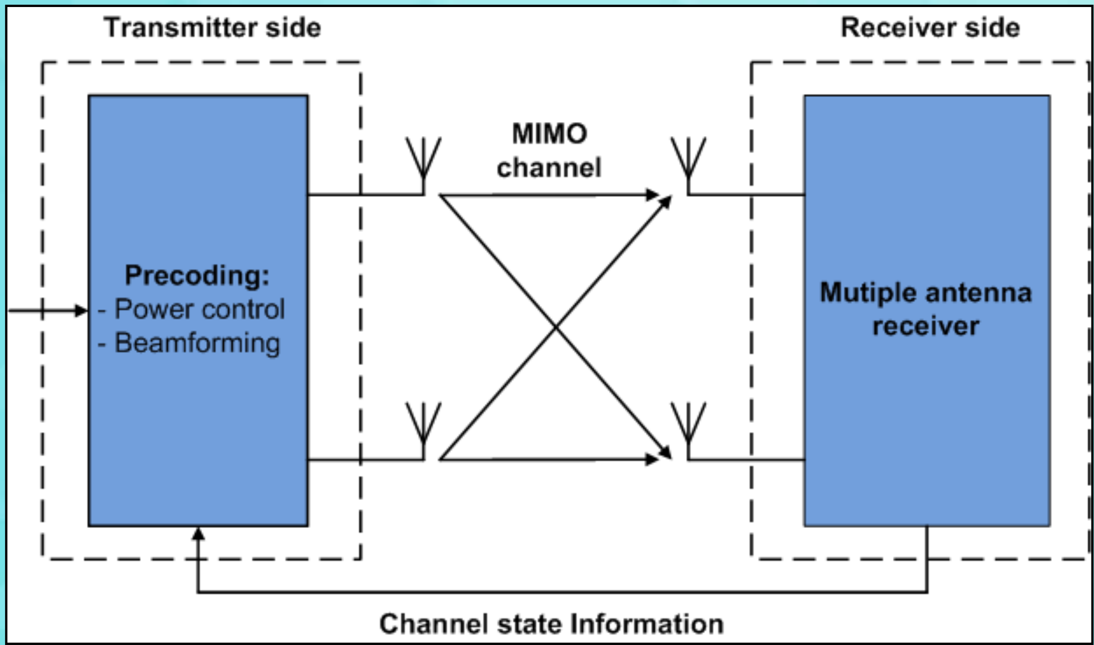



# 2. PRECODING TECHNIQUE FOR MIMO SYSTEMS

**Precoding** – weighting transmitter data symbols by addition complex-value weights to encoded symbols at the transmitter side.

**Precoding technique based on** channel knowledge at the transmitter side (CSIT) which provides to manage transmitter power and calculate beamforming weights **to obtain the highest capacity and interference suppression**.




Precoding and channel state information

# 4. PRECODING TECHNIQUE FOR MIMO SYSTEMS

**Results of simulation illustrates energy gain of proposed method about 2 dB.**

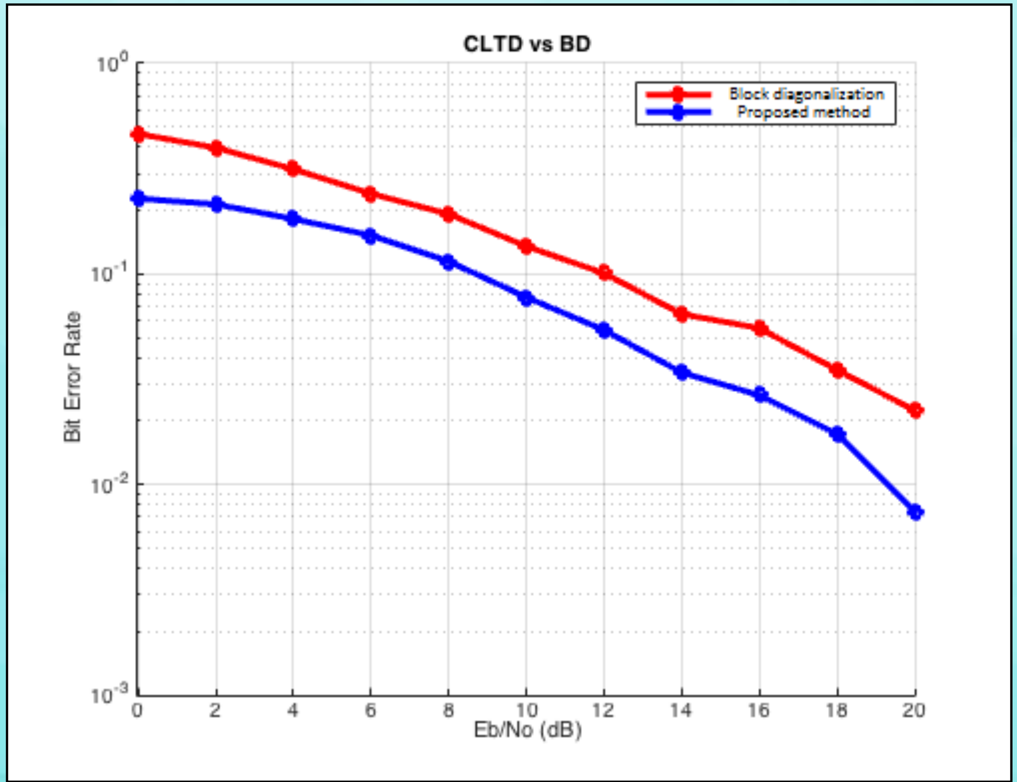
The main goals of precoding technique development:

1) increasing of energy gain;

2) increasing of capacity;

3) increasing of noise immunity;

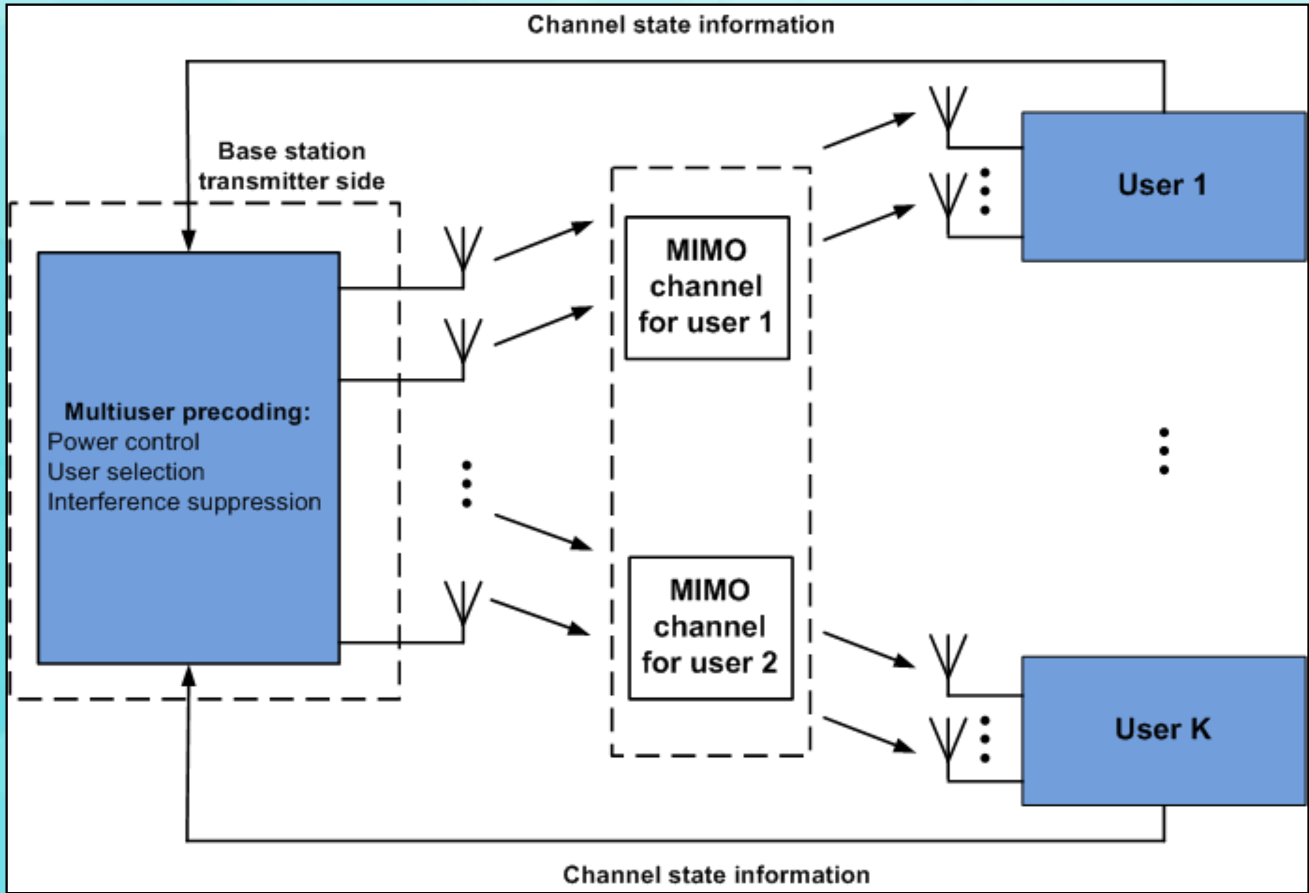
4) decreasing of computational complexity.




## Simulation conditions

| | |
|---|---|
| Antenna configuration | 4x4 |
| Channel | MIMO Rayleigh fading channel |
| Channel encoding | Convolutional encoding (rate 3/4) |
| Modulation | 16QAM |

# 5. PRECODING TECHNIQUE FOR MIMO SYSTEMS




**Multiuser MIMO systems with precoding at the base station side based on user feedback**

# 6. PRECODING TECHNIQUE FOR MIMO SYSTEMS

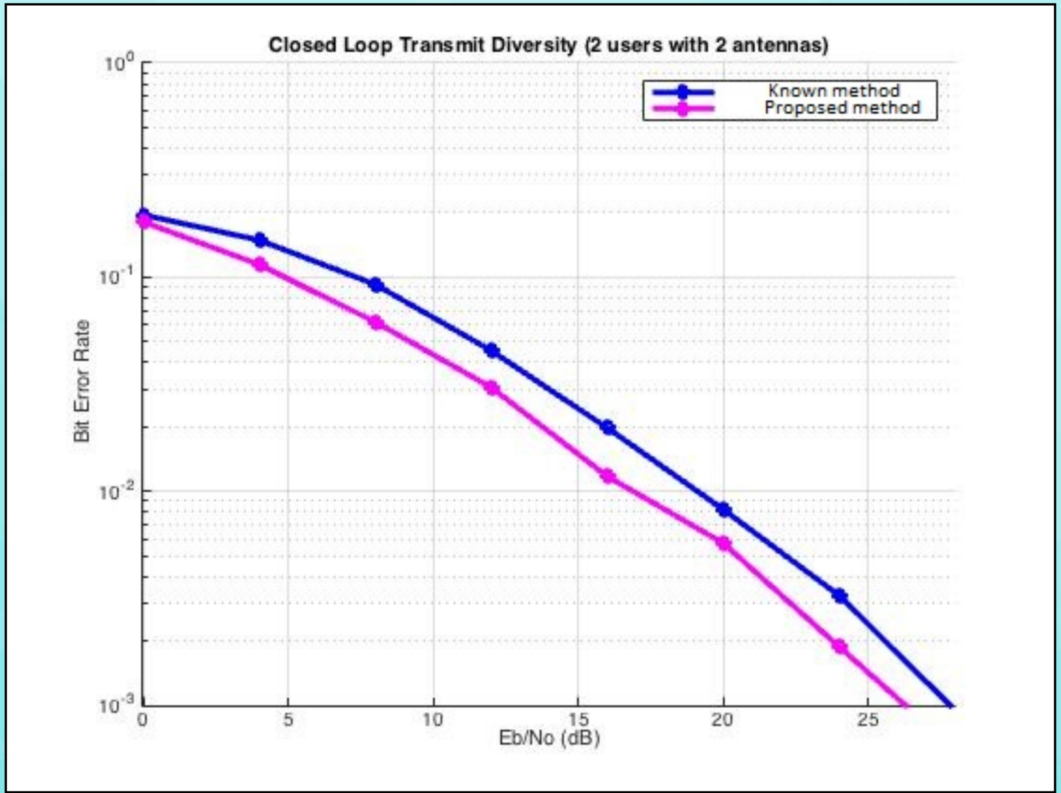
**Results of simulation illustrates energy gain of proposed method about 2 dB.**

The main goals of multiuser precoding technique development:

1) suppression of multiuser interference
2) increasing of energy gain,
3) increasing of capacity
4) increasing of noise immunity
5) decreasing of computational complexity

## Simulation conditions

| | |
|---|---|
| Antenna configuration | Base station: 4 Tx<br>User: 2 Rx<br>Number of users: 2 |
| Channel | MIMO Rayleigh fading channel |
| Channel encoding | Convolutional encoding (rate 3/4) |
| Modulation | 16QAM |




**Simulation results of proposed by us method allows increasing multiuser precoding efficiency**

# 7. DECREASING OF COMPUTATIONAL COMPLEXITY OF DEMODULATION ALGORITHMS FOR MASSIVE MIMO SYSTEMS

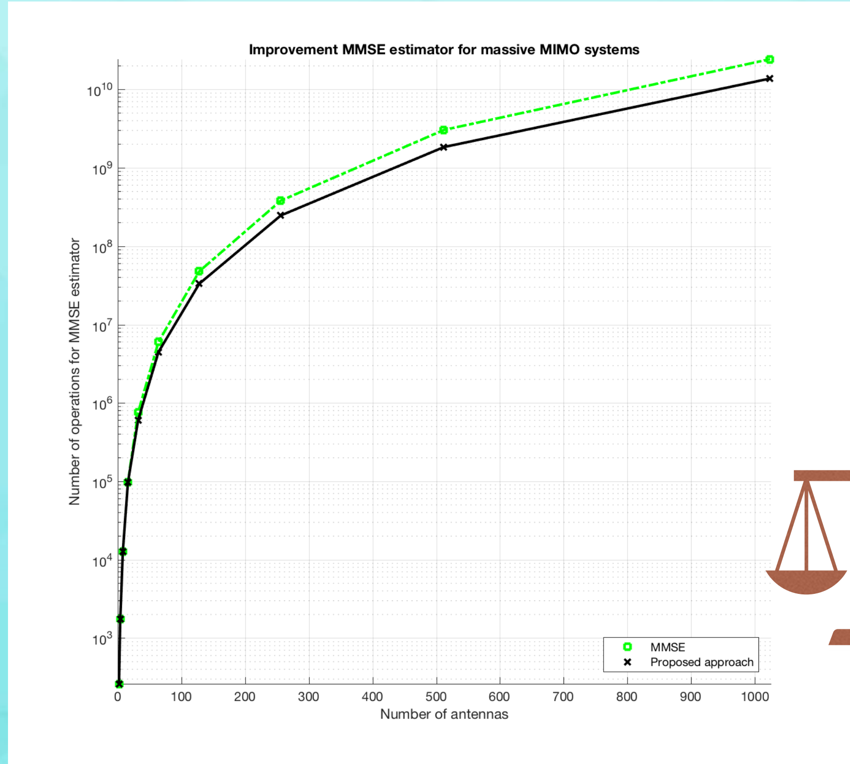
***Problem to solve:*** **extremely high level of the computational complexity** in obtaining of the estimate of the vector of transmitted symbols applying known algorithms used for the purpose of demodulation at the receiver side in **massive MIMO systems**:

- ***The MMSE demodulation algorithm is the basic one for massive MIMO systems*** due to low computational expenses as compared with the Maximum Likelihood (ML) method; it also possesses a higher resistance to noise as compared with the Zero-Forcing (ZF) method.

Our development is approach that require **less number of elementary arithmetical operations for obtaining of the MMSE estimate** for the vector of transmitted symbols at receiver.

# 8. DECREASING OF COMPUTATIONAL COMPLEXITY OF DEMODULATION ALGORITHMS FOR MASSIVE MIMO SYSTEMS

Using of different methods of fast multiplication of the matrices allows ***decreasing the number of elementary arithmetical operations by up to 44%*** as compared to the traditional MMSE method depending upon the number of antennas without losing in the resistance to noise




Efficiency of applying fast matrix multiplication in MMSE estimator

# 9. DEVELOPMENT OF DEMODULATION TECHNIQUES FOR MASSIVE MIMO SYSTEMS

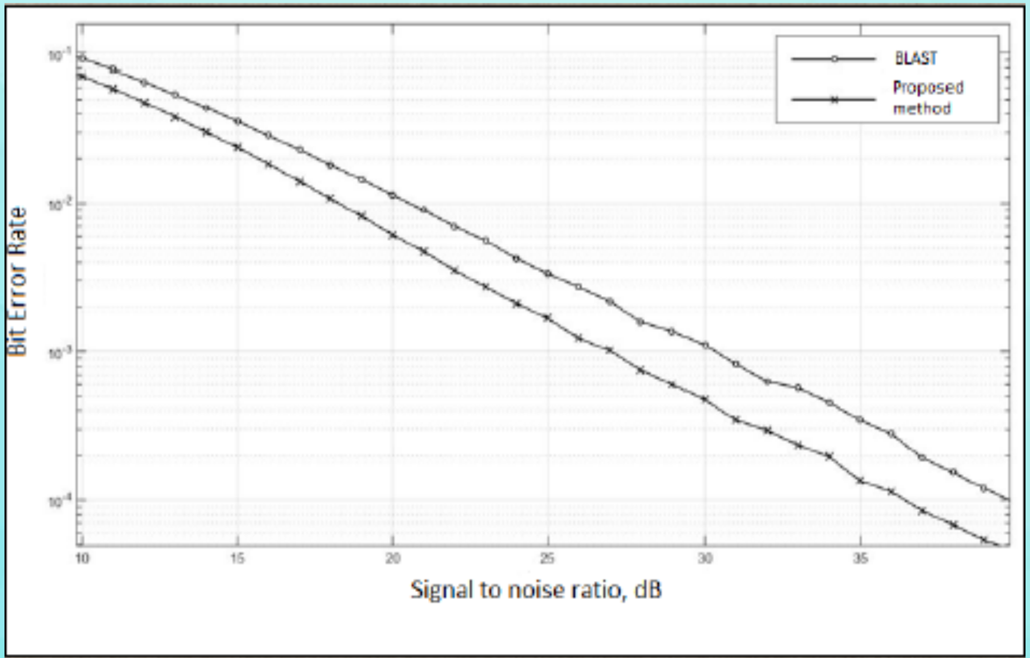
***Problem to solve:*** **develop a new demodulation technique** having lower computational expenses and lower resistance to noise as compared with the MMSE method:

- Let us consider ***the number of arrays at the receiver end and the number of arrays at the transmitter*** end are equal; that is ***N***.
- ***The MMSE demodulation algorithm has cubic computational complexity O($N^3$).*** The above computations have to be performed during the period of time, which is not exceeding the duration of one informational symbol.
- ***Large-size MIMO systems*** it is typical to have ***a large dimensionality of the matrix*** of complex transmission coefficients of the telecommunication channel, in particular, ***N>>32***.

# 10. NEW SPACE TIME CODES

Results of simulation illustrate that applying STC matrices proposed by us provided to obtain 1.2 - 2 dB energy gain in comparison with known method BLAST.

Open question: Development of new STC matrices for high capacity massive (Large Scale) MIMO systems



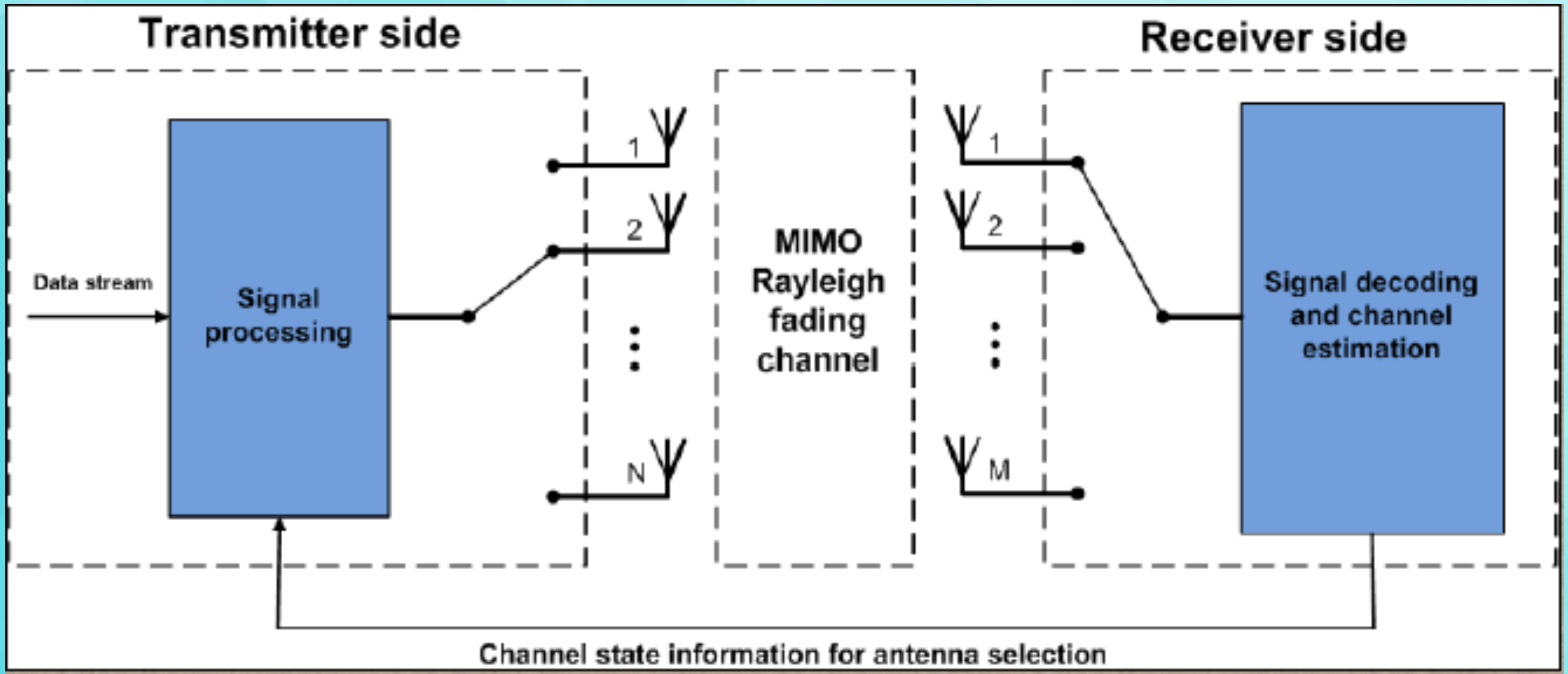

Comparison of efficiency of known BLAST and proposed method applying space time code

Simulation conditions

| | |
|---|---|
| ANTENNA CONFIGURATION | 8X8 |
| CHANNEL | MIMO RAYLEIGH FADING CHANNEL |
| MODULATION | 16QAM |

# 11. ANTENNA SELECTION IN MIMO SYSTEMS

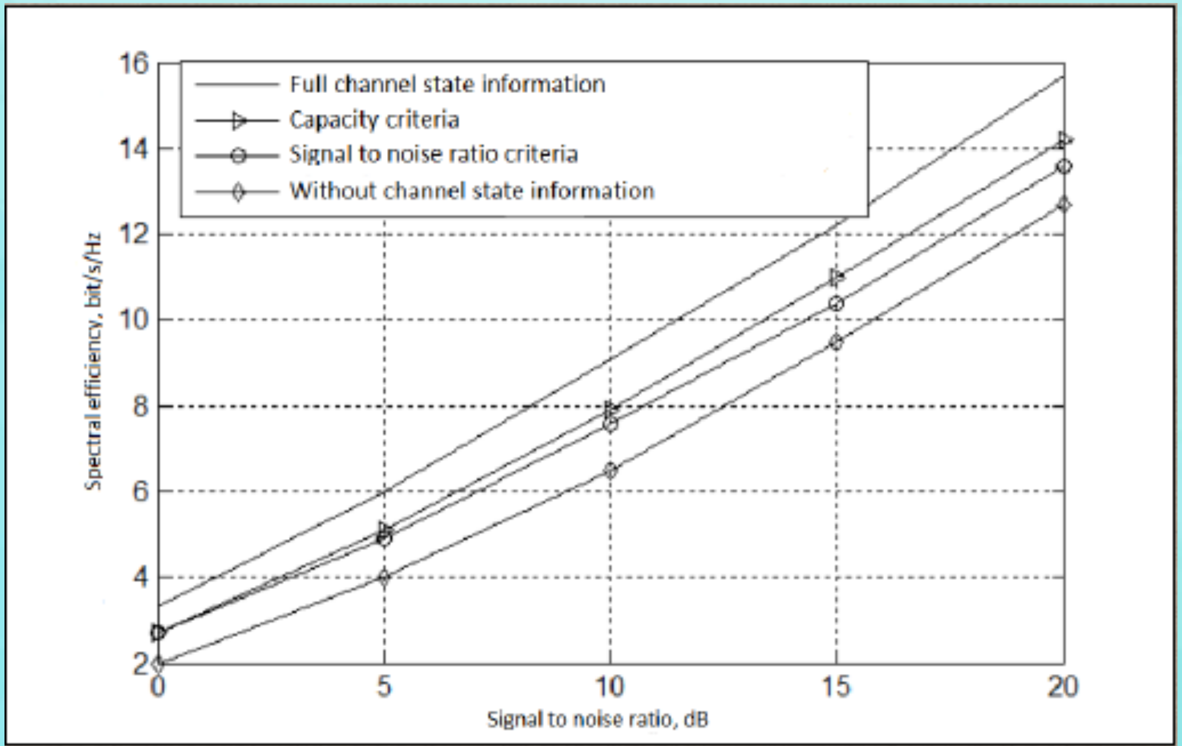
**Antenna selection** is a promising technology for MIMO systems that allows the selection of transmit and receive antennas based on channel state information to achieve the highest capacity and noise immunity




Feedback channel information and antenna selection

# 12. ANTENNA SELECTION IN MIMO SYSTEMS

Result of simulation illustrates:
1) capacity gain **40-60%** by applying full channel state information on transmitter side for antenna selection
2) capacity gain **25-30%** of applying capacity criteria for antenna selection
3) capacity gain **10-15%** of applying signal to noise ratio criteria for antenna selection




Comparison of efficiency of different antenna selection criteria

## Simulation conditions

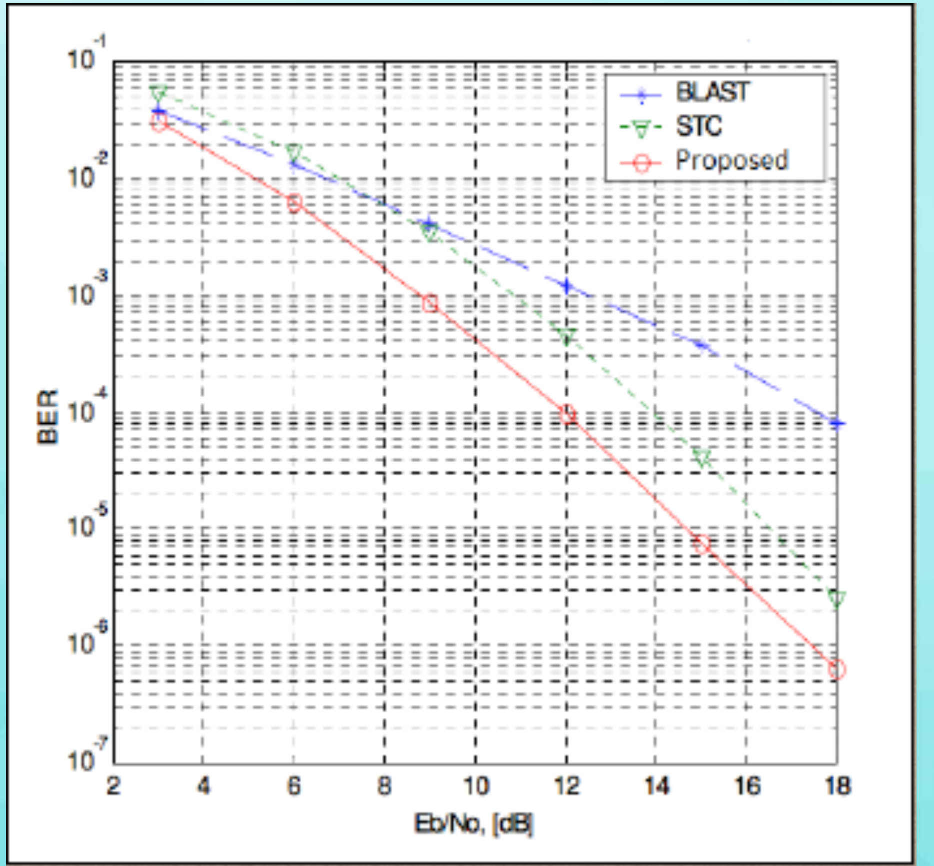
| | |
|---|---|
| ANTENNA CONFIGURATION | 8X8<br>NUMBER OF SELECTED ANTENNAS: 2 |
| CHANNEL | MIMO RAYLEIGH FADING CHANNEL |
| MODULATION | 16QAM |

# 13. MIMO DETECTION

Results of simulation illustrate that method for spatial signal detection proposed by us provided to obtain 2 dB energy gain in comparison with existing BLAST and STC

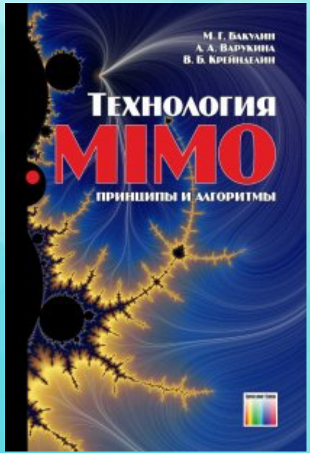
Simulation conditions

| | |
|---|---|
| ANTENNA CONFIGURATION | 2X2 |
| CHANNEL | MIMO RAYLEIGH FADING CHANNEL |
| MODULATION | 16QAM |

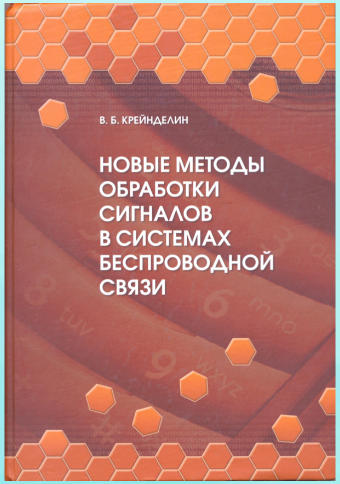



Comparison of different existing detection methods and method proposed by us

# 14. OUR PUBLICATIONS (IN RUSSIAN)









# 15. OUR PATENTS

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World Intellectual Property Organization
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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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A1

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(71)Applicant:
**NORTEL NETWORKS LIMITED** World Trade Center of Montreal, 380 St. Antoine Street West, 8th Floor, Montreal, Québec H2Y 3Y4; (CA). [CA/CA].*(for all designated States except US)*

(72)(75)Inventors; and Inventors/Applicants:
**WANG, Rui, R.** 1204-900 Dynes Road, Ottawa, Ontario K2C 3L6; (CA) [CA/CA].**TONG, Wen** 904-1000 Castle Hill Crescent, Ottawa, Ontario K2C 3L7; (CA) [CA/CA].**SHINAKOV, Yuri S.** ul. Vilnusskaya, 7-2-125, Moscow, 117574; (RU) [RU/RU].**CHLOMA, Alexandre M.** ul. Gagarina, g. Zhukovsky, Moskovskaya oblast, 140160; (RU) [RU/RU].***BAKOULINE*, Mikhail G.** ul. Kirova, 35-31, Podolsk, Moskovskaya oblast, 142110; (RU) [RU/RU].**KREINDELINE, Vitali B.** ul. Grajvoronosvkaya, 8-1-87, Moscow, 109518; (RU) [RU/RU].

(74) Agent
**KLJUKIN, Vyacheslav Alexandrovich** Prechistensky pereulok 14-1, Moscow, 119034; (RU).

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(84) Designated States (regional)
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(54) Title CELLULAR COMMUNICATIONS SYSTEM RECEIVERS

(57) Abstract
An impulse response matrix of a received signal in a TDMA communications system is approximated using a plurality of indirect variables of a linear complex vector. The indirect variables are used for synchronizing to the received signal (14A, 14B) and for tracking (16A, 16B) and frequency offset estimation (22) during successive samples of the received signal, the samples being equalized in dependence upon the indirect variables (18). A demodulated signal (28) is derived from the equalized signal samples. Individual synchronization (14A, 14B) and tracking units (16A, 16B), and a single equalizer (18), can be provided for a two-antenna receiver. Tracking errors can be used to adapt a parameter of the equalizer to reduce interference in the received signal (30).

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(12) **United States Patent**
**Tong et al.**

(10) **Patent No.:** **US 6,298,461 B1**
(45) **Date of Patent:** **Oct. 2, 2001**

(54) ENCODING AND DECODING METHODS AND APPARATUS

(75) Inventors: **Wen Tong**; **Rui Wang**, both of Ottawa (CA); **Vitali B. Kreindeline**, Moskva (RU); **Mikhail G. Bakouline**, Moskovskaja (RU); **Alexandre M. Chloma**, Koskovskaja (RU); **Yuri S. Shinakov**, Moscow (RU)

(73) Assignee: **Nortel Networks Limited**, Montreal (CA)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/236,070**

(22) Filed: **Jan. 25, 1999**

(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**[7] .................... **H03M 13/00**
(52) **U.S. Cl.** .................... **714/755**; 714/784; 714/795
(58) **Field of Search** .................... 714/755, 786, 714/746, 760, 784, 792–794, 795, 788; 455/12.1, 21; 370/342, 494, 463, 467, 496; 375/130, 261–262; 341/107; 379/90.01, 93.08

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US007280466B2

(12) **United States Patent**
**Tong et al.**

(10) **Patent No.:** **US 7,280,466 B2**
(45) **Date of Patent:** **Oct. 9, 2007**

(54) TRANSMITTER FOR A WIRELESS COMMUNICATIONS SYSTEM USING MULTIPLE CODES AND MULTIPLE ANTENNAS

(75) Inventors: **Wen Tong**, Ottawa (CA); **Yuri S. Shinakov**, Moskow (RU); **Alexandre M. Chloma**, Moskovskaja Oblast (RU); **Mikhail G. Bakouline**, Moskovskaha Oblast (RU); **Vitali B. Kreindeline**, Moskow (RU)

(73) Assignee: **Nortel Networks Limited**, St. Laurent, Quebec (CA)

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(22) Filed: **Apr. 5, 2002**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
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(52) **U.S. Cl.** .................... **370/208**; 370/536; 375/146
(58) **Field of Classification Search** .................... 370/208, 370/209, 335, 342, 535, 536, 542, 543, 544; 375/299; 455/101
See application file for complete search history.

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*Primary Examiner*—Chi Pham
*Assistant Examiner*—Kevin Mew

(57) **ABSTRACT**

In a transmitter of a wireless communications system having M transmit antennas (**10**), each transmit antenna is supplied with a respective combined signal comprising a respective one of M groups each of N data sub-streams, orthogonally spread by N Walsh code sequences (W**1** to WN). The N orthogonal code sequences used for each of the M groups comprise a respective one of M different combinations of N from $N_w$ orthogonal code sequences, where $N_w$>N. M and N are integers greater than one. The combined signals can also include orthogonally spread pilot signals (WP) for channel estimation at a receiver. Orthogonality of the signals transmitted from the transmit antennas is increased, so that transmit signal power can be decreased and/or the receiver can have fewer than M receive antennas.

**25 Claims, 3 Drawing Sheets**

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(71)Applicants:
**NORTEL NETWORKS LIMITED** 2351 Boulevard Alfred Nobel, St. Laurent, Quebec H4S 2A9; (CA). [CA/CA].*(for all designated States except US)* **WANG, Chao** 1204-900 Dynes Road, Ottawa, Ontario K2C 3L6; (CA). [CA/CA].

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(74) Agent
**KLIUKIN, Viacheslav Alexandrovich** Gowlings International Inc., Prechistensky pereulok, 14-1, Moscow, 119034; (RU).

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(84) Designated States (regional)
ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG)

For information on time limits for entry into the national phase please click here

Published
*with international search report*

(54) Title METHODS AND APPARATUS FOR TURBO SPACE-TIME TRELLIS CODING

(57) Abstract
Space-time diversity using a plurality of transmit antennas (16, 18) is provided with a turbo coding arrangement comprising two recursive systematic convolutional coders (30, 32), to one of which input bits are supplied directly and to the other of which the information bits are supplied after interleaving (34) of bit groups for respective symbol intervals. Symbols produced by the coders and comprising systematic and parity information are supplied to paths to the antennas alternately in successive symbol intervals to provide the space-time diversity. Arrangements are described for 2 and 4 antennas and for various convolutional codes, and an iterative decoder is also described.

# Thank you for your attention!

***Any questions?***

Speaker:
Taoufik BEN REJEB
Ph.D, Associate prof.
t.benrejeb@mtuci.ru