Communication Using an OR Channel

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Offen im Denken

OR

At the occasion of

the 2015 Aaron D. Wyner Distinguished Service Award

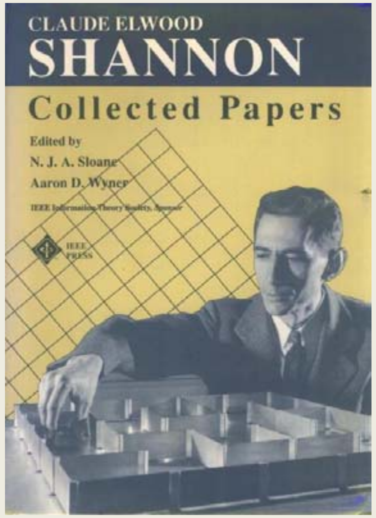
The Aaron D. Wyner Distinguished Service Award honors individuals who have shown outstanding leadership in —and provided long-standing exceptional service to — the IEEE Information Theory Community.

Han Vinck is receiving the award for his longstanding contributions with IEEE chapters, promotion of information theory and its applications, and organization of conferences and workshops.

IEEE Information Theory Society

Road map

1. access for the OR channel using information theory
   – Fundamental limits for communication using the OR channel (Shannon)



2. Signature transmission

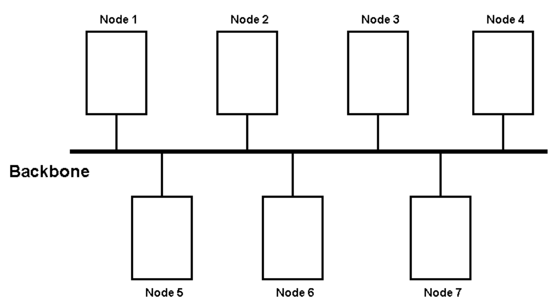
3. Protocol sequences

Problem: uncoordinated users sharing the same medium

- Ex: RFID tags

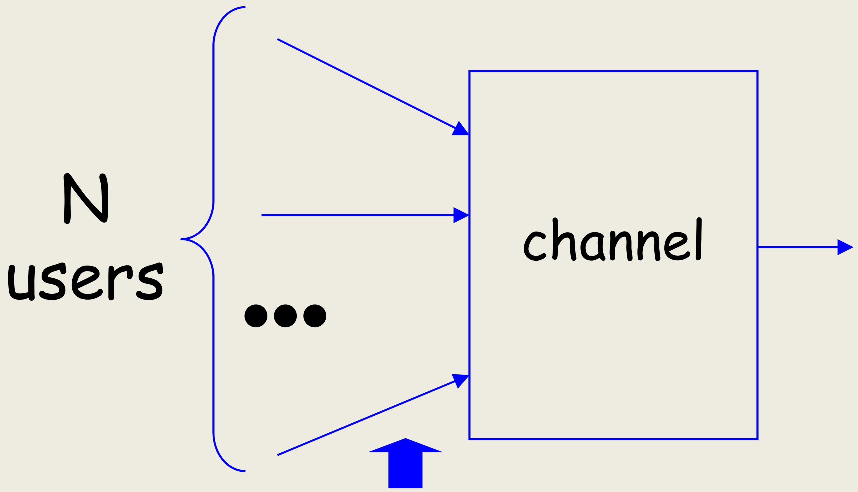
- Ex: Computer communication using a bus system

Figure 2 Bus Network Topology



Difference between controlled and un-controlled

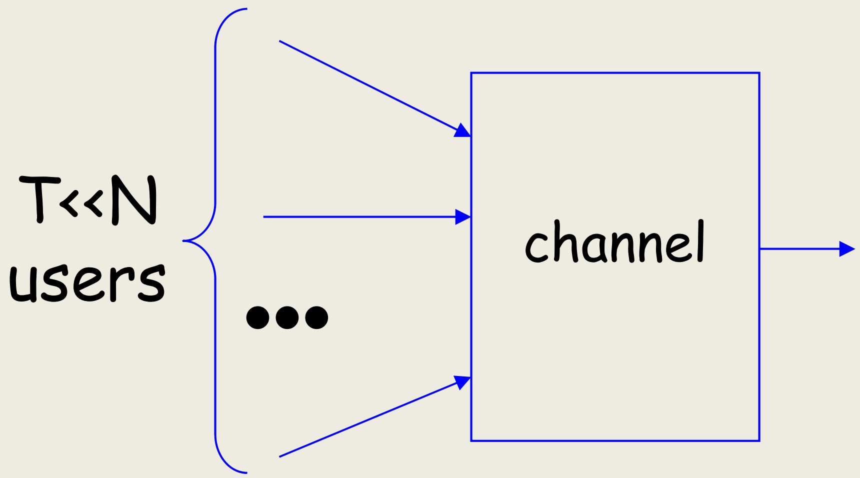
classical (information theory)



Controlled access

Active users know each other

random access (networking)



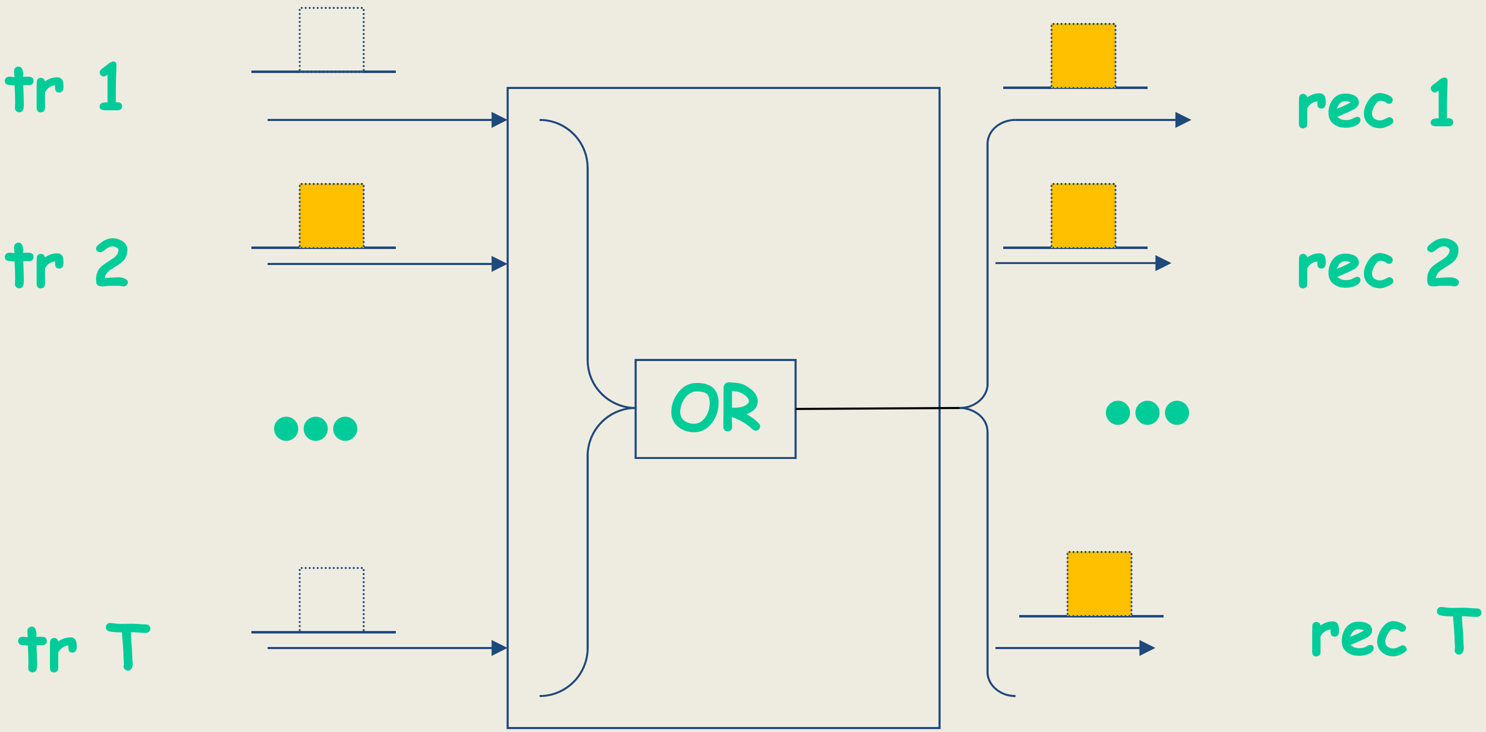
No control

Active users do not know who

assumption: the number of active users is small (as in telephony)

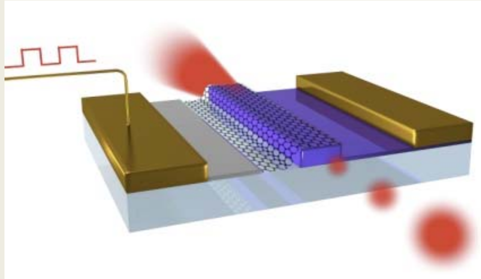
What is the channel model ?
(energy detection, Photon counting)

binary in- binary out



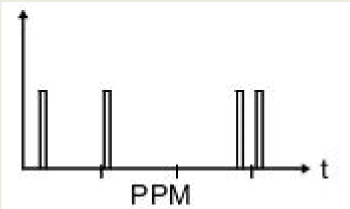
Only T out of N possible users are active: - users do not know who

Where does the OR model come from ?

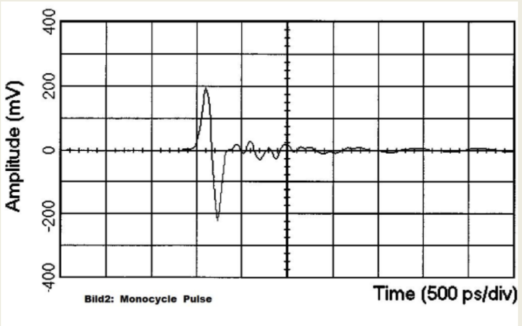


- Optical On-Off channel model
- CAN Bus communications

  (CAN = Controller Area Network)

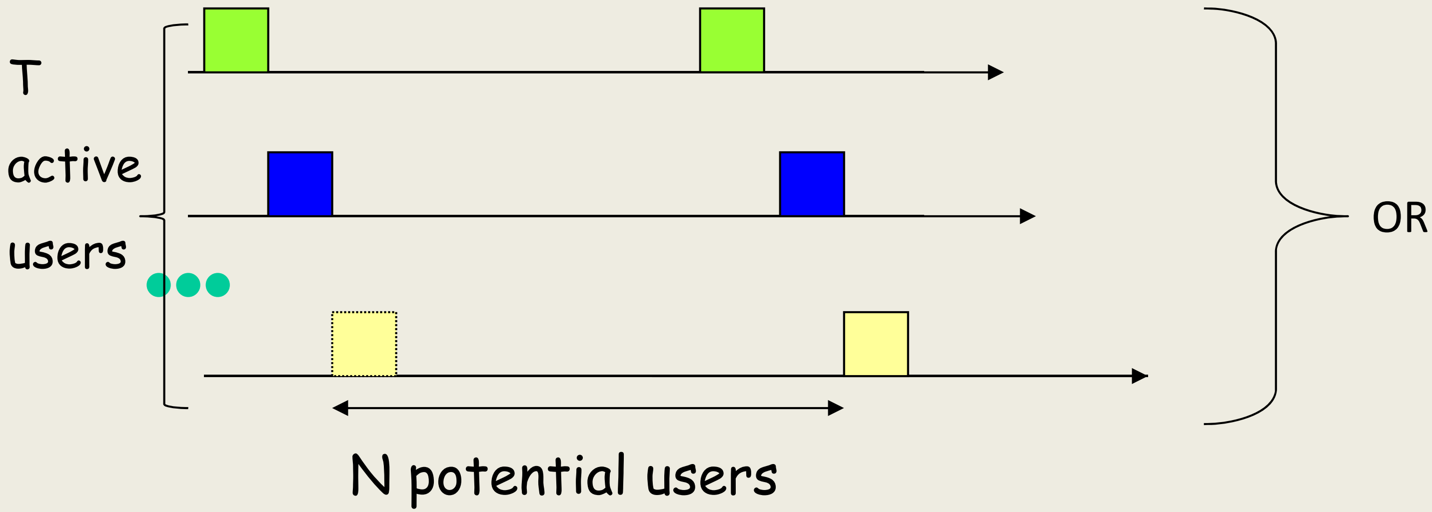


- Frequency Hopping sequence design
- Pulse Position Modulation
- UWB



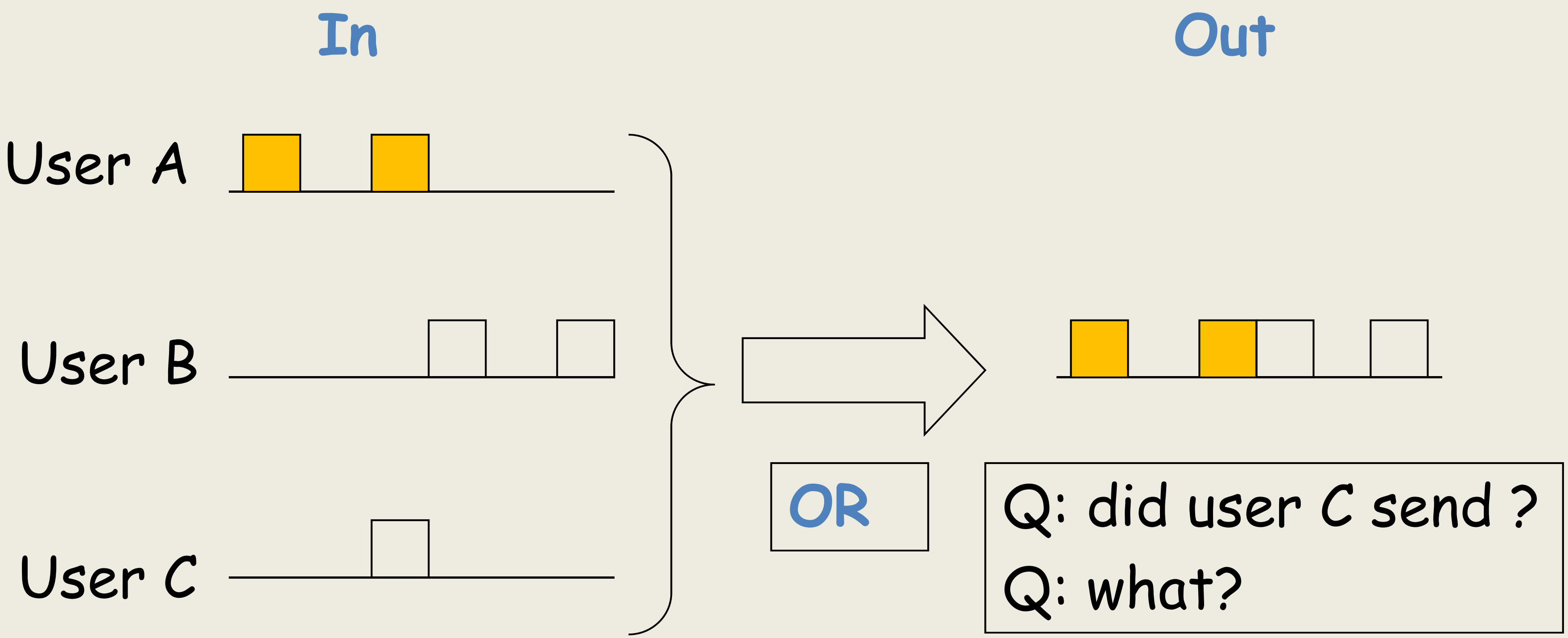
A simple way to transmit: Time-Division Multi Access TDMA

Every possible user gets a particular time slot

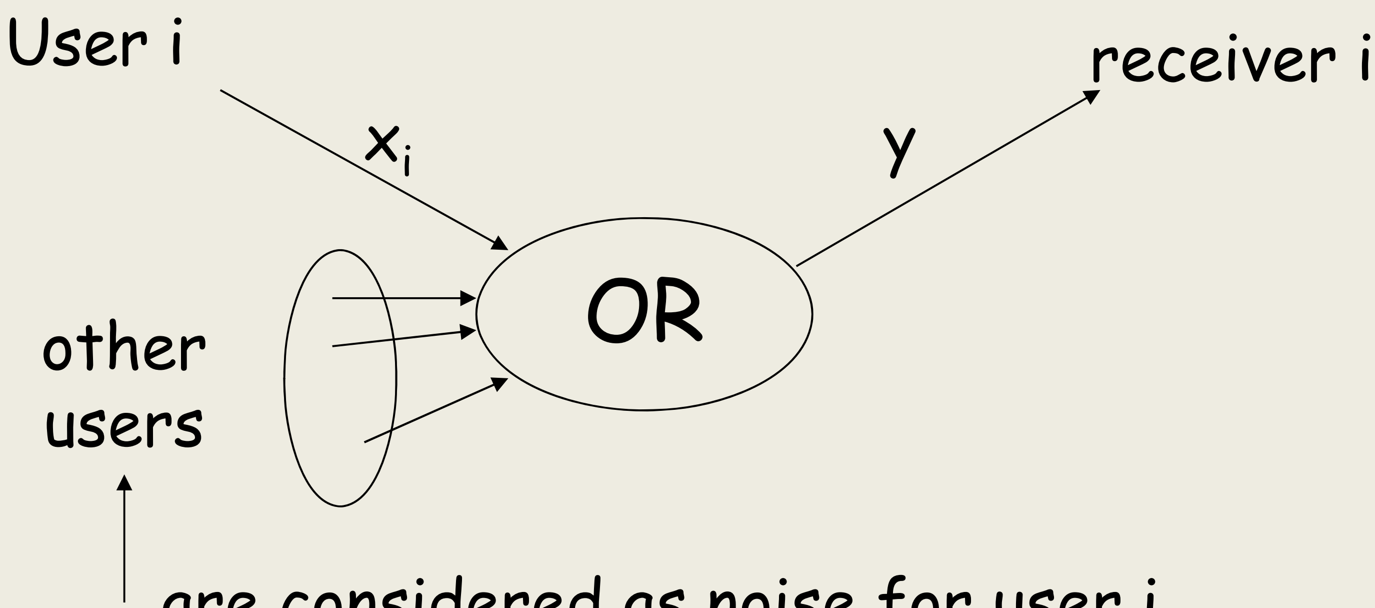


- efficiency = **T/N** **inefficient, but easy**

Random-Access problem statement



The model from an information theory point of view

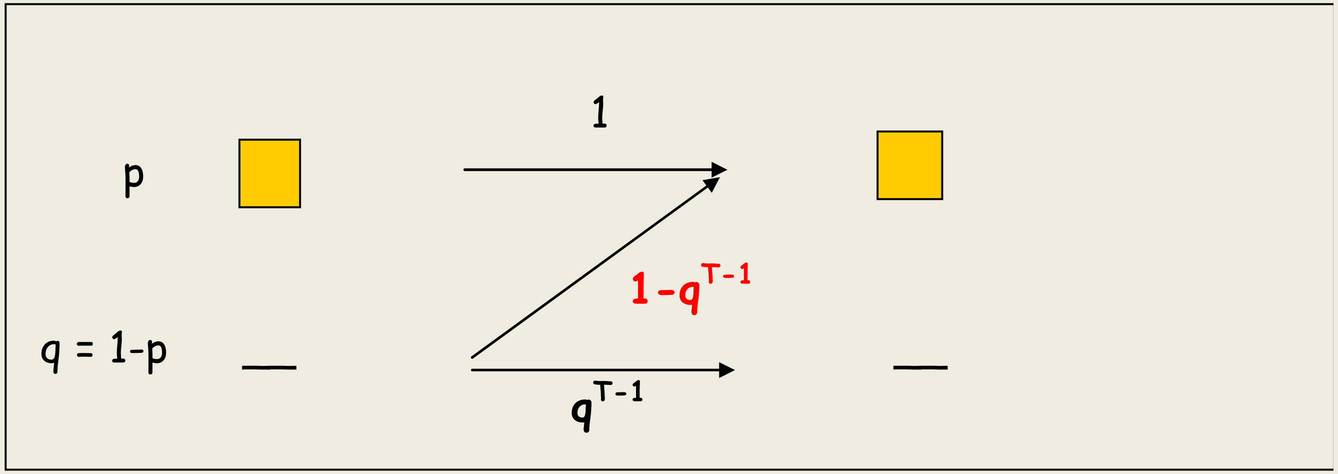


are considered as noise for user i

$$\text{sum capacity} = T \max_{p} I(X_i;Y)$$

- Under the condition that all T users behave in the same way

Communication model for a particular user looks like



$$C = T \cdot \max_{p} I(X_i;Y) \Rightarrow C_{T\to\infty} = \ln 2 \text{ bits/tr.}$$

for $p = \ln 2/T$

references:

A.Cohen, J. Heller and A.J. Viterbi, „A new coding technique for *asynchronous* multiple access communications," IEEE Tr. on Communications., pp. 849-855, Oct. 1971

A.J. Han Vinck and K. Keuning, "On the capacity of the asynchronous T-user M-frequency noiseless multiple-access channel *without intensity information*," IEEE Tr. on Information theory, pp. 2235-2238, 1996

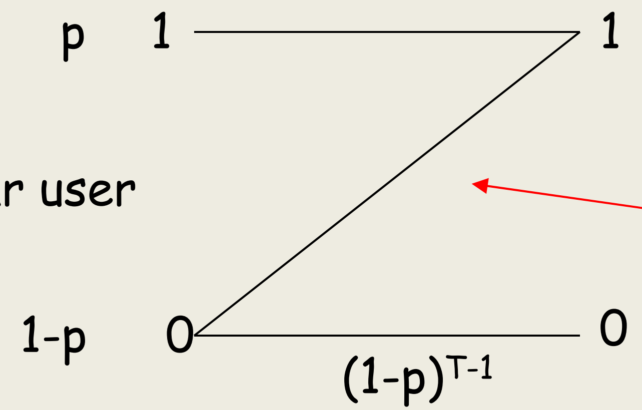
To calculate the capacity is difficult in general

<u>REASON:</u>

Channel transition probabilities are a function of the input probabilities

<u>Note:</u> classical information theory **does not** work here!

Channel for a particular user



interference from others

depends also on p!

Problem is not convex anymore

CONCLUSION for T uncoordinated access

– OR channel: $C_{T\to\infty} = \ln 2 \approx .7$ bits/tr.; for $P_1 = \ln 2/T$

- We lose only 30% compared with fully coordinated (TDMA)!

=> code books needed with long - low weight- codewords!

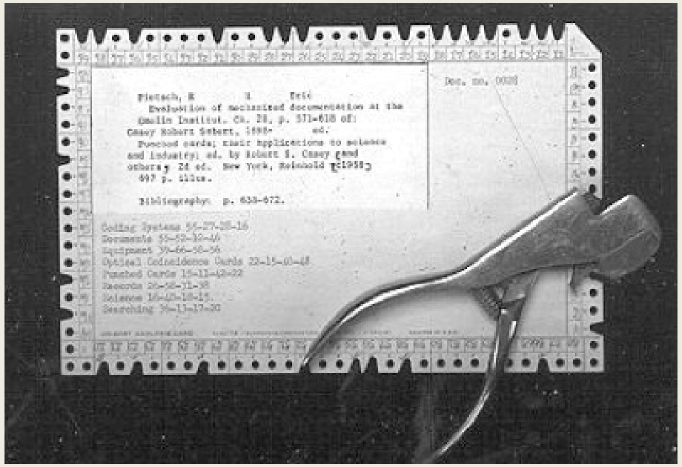
=> For the XOR channel: $C_{T\to\infty} \geq 0.38$ bits/tr. (open problem!)

- Why do we use the XOR operation in network coding ?

P. Gober, A. J. H. Vinck. "Note on 'On the Asymptotic Capacity of a Multiple Access Channel' by L. Wilhelmsson and K. Sh. Zigangirov'." *Problems of Information Transmission [Problemy Pederachi Informatsii]*, vol. 36, no. 1, pp. 19-22, 2000.

Look at an old data bank (library, …)

- Item properties are **coded** as non-holes on the card



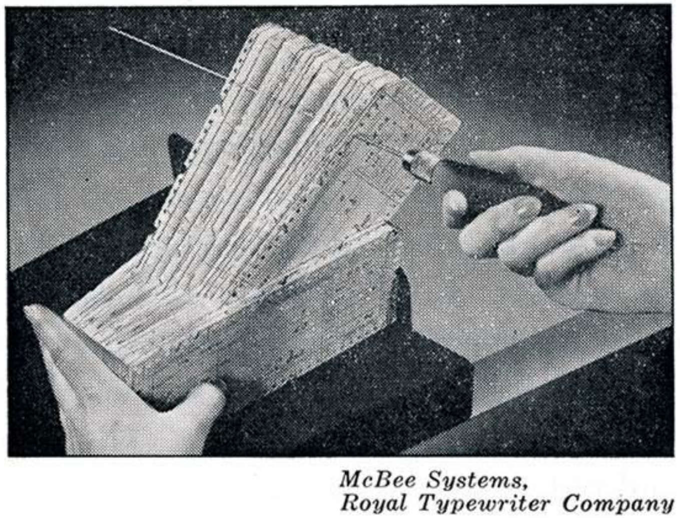


Figure 9-11. McBee Key-Sort

- Cards selection by pins
- Problems:
  - Properties do not overlap, otherwise too many faulty seletions
  - how to code many properties for limited space

- **We see the DIFFERENCE** between HARD and SOFTWARE

How to get a practical system?
(Task of an engineer is to solve problems)

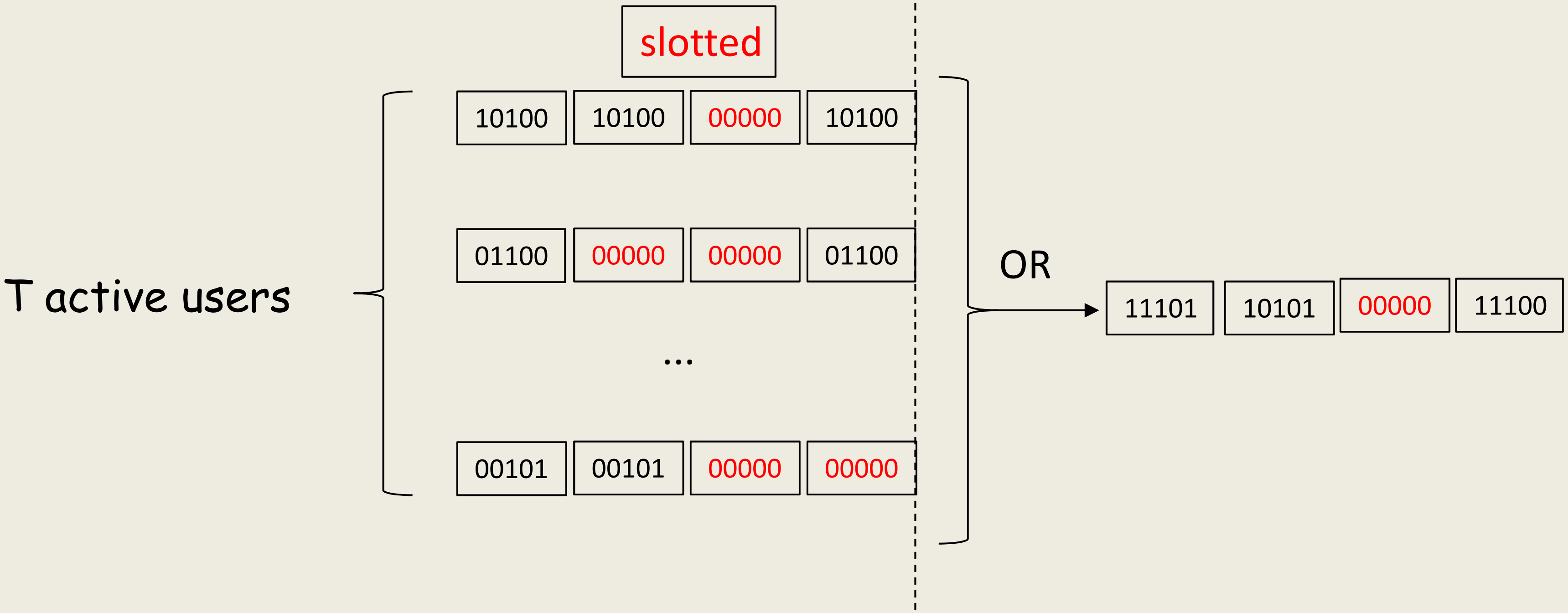
- Transmission using **signatures:**
  - Coordinated and uncoordinated

Ex: 1:= 1 0 0 1 1 0 0 1 and 0:= 0 0 0 0 0 0 0 0

- Transmission using a **protocol**

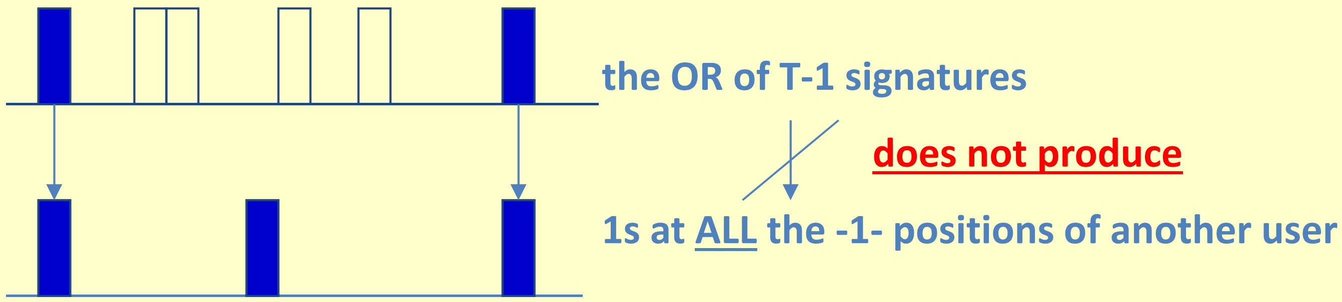
Let us look at the following transmission scenario

- Users can transmit all *zero sequence* or a *signature sequence*
- Users do not know each other



Detector for user i looks for the presence of his signature

When do we have a correct detection ?



Problem:

- how to distribute the signatures s.t. any set of < T active users **does not produce** a valid signature for a non active user?

Example: up to 2 active users; n = 9; N = 12

User	signature
1	001 001 010
2	001 010 100
3	001 100 001
4	010 001 100
5	010 010 001
6	010 100 010
7	100 001 001
8	100 010 010
9	100 100 100
10	000 000 111
11	000 111 000
12	111 000 000

R = 2/9

TDMA gives R = 2/12

Example:

011 101 101 = x OR y ?

$\ln 2/T \approx 1/3$

What are the problems to work on?

- Constructions? Bounds for blocklength n(T,N) ?

$$T \log_2 N < n < 3\, T^2 \log_2 N \quad \text{(asymptotic result)}$$

at least, every user has to sends his identity

References:

Cover-Free Families and Superimposed Codes: Constructions, Bounds, and Applications to Cryptography and Group Testing
by Arkadii D'yachkov, Vladimir Lebedev, Pavel Vilenkin, Sergei Yekhanin
ISIT2001, Washington, DC, June 24{29, 2001

This paper deals with cover-free families or superimposed codes. They generalize the concept of superimposed s-codes and have several applications for cryptography and group testing. We present a new asymptotic bound on the rate of optimal codes and develop some constructions.

Challenge RFID for multi user

Printable Depolarizing Chipless RFID Tag Based on DGS Resonators for Suppressing the Clutter Effects

Maher Khaliel[1,2], Mohamed El-Hadidy[1] and Thomas Kaiser[1]
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[2]Ain Shams Faculty of Engineering, Ain Shams University, Cairo, Egypt
maher.mohamed@uni-due.de

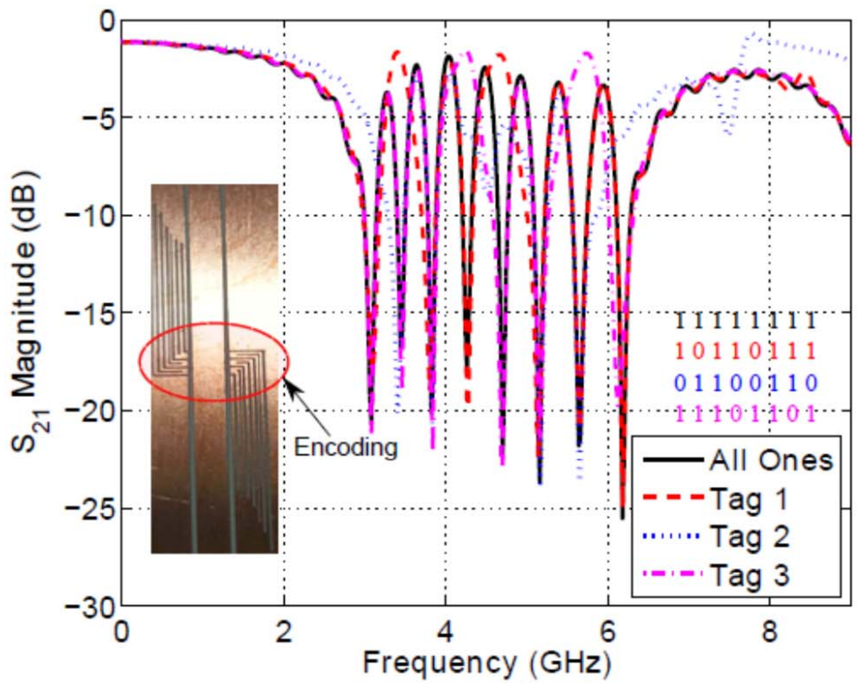


Fig. 7: Chipless RFID tag encoding methodology and various codes.

Some research problems:

- code design for **T tags simultaneously**?
  - realistic N and T (bound $T\log_2 N$)
- Combination with **error correction**?
- **Interference** problem?

Extension from 2-ary to M-ary with a surprising result

- Binary OR   0 +1 = 1, 1 + 1 = 1, 0 + 0 = 0

- **For PPM**: symbols have a single pulse in M positions

symbol „OR“:   (00010) + (10000) = (10010)

- we can obtain the **same** random access capacity   (ln2)
- not many code constructions

Reference:
On Superimposed Codes in *Numbers, Information and Complexity, Ingo Althöfer at.* Kluwer Academic Publishers, February 2000, pp. 325-331, A.J. Han Vinck and Samwel Martirosyan


Samwel Martirosyan, armenia

Application in M-FSK frequency hopping or UWB

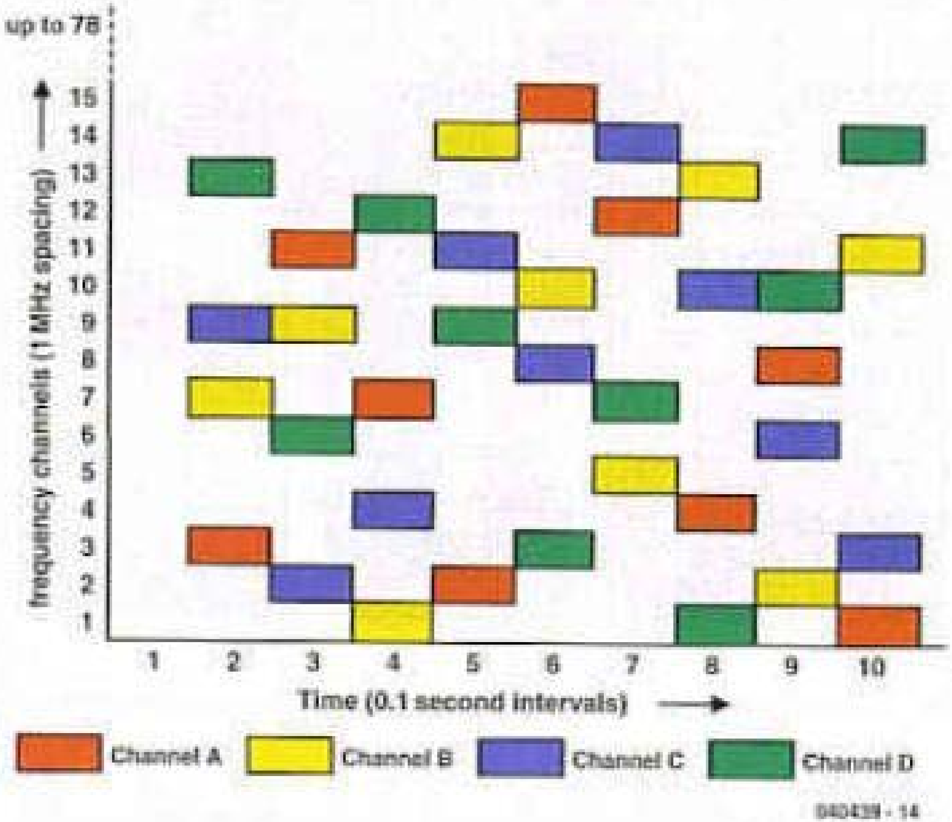


Figure 4.
Frequency hopping allows each frequency to be used by several channels.

Allow overlap

=> Higher efficiency

PPM is not new

used by the acient Greeks as an optical signaling PPM
known as the Hydraulic telegraph of Aeneas

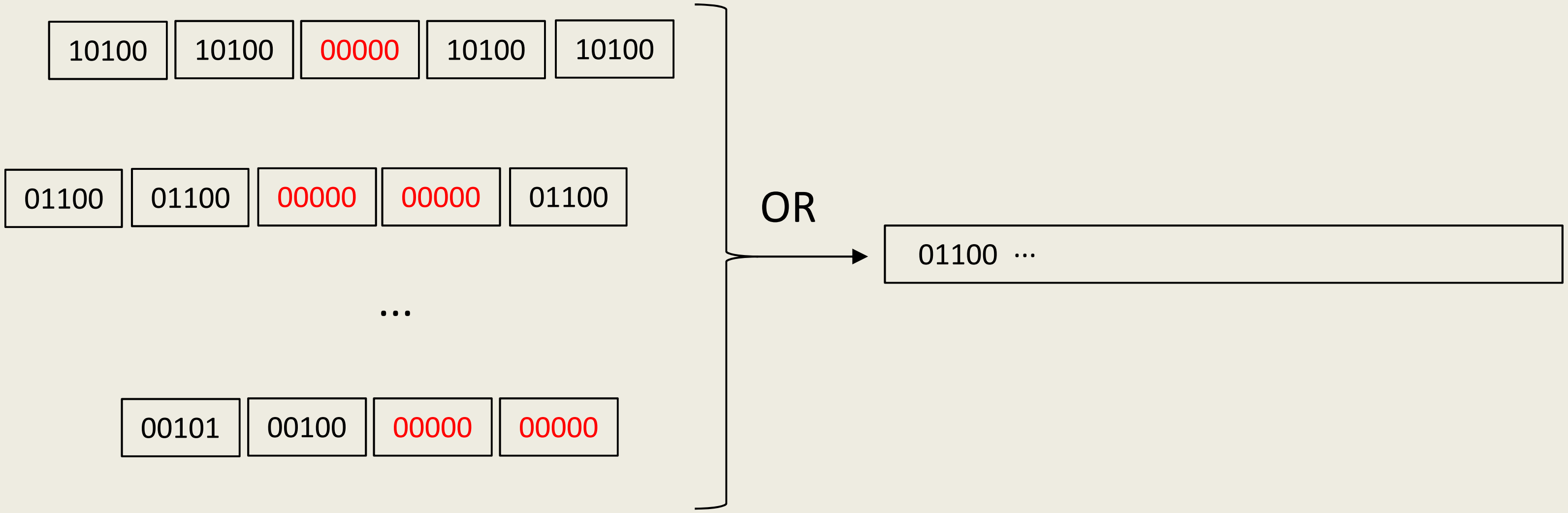
More possible applications

- Multiple RFID tag identification
    - is an example of OR communication

- protocol sequences (to be discussed later)
- All Optical receiver for speed improvements

Let us look at the following transmission scenario

- Users can transmit all *zero sequence* or a *signature sequence*
- Users do not know each other and there is no word synchronization



Detector for user i looks for the presence of his signature

What is the problem?

- **Shifted** signatures should not generate a valid signature

  - Example: … **1 0 0 1 0 1 0 0 …** **user 1**

    … 1 0 1 0 1 0 0 0 … user 2

    … 1 0 1 0 0 0 1 0 … user 3

Definition of Optical Orthogonal Codes (OOC)

__Definition 1:__ A set C of n-length binary vectors of weight w

$$\mathbf{x} = (x_1, x_2, \cdots, x_n)$$

composes an $(n, w, \lambda_a, \lambda_c)$ OOC if the following

auto-correlation
$$\sum_{t=1}^{n} x_t x_{t+\tau} \le \lambda_a, \quad \tau \ge 1 \tag{1}$$

and

cross-correlation
$$\sum_{t=1}^{n} x_t y_{t+\tau} \le \lambda_c, \quad \tau \ge 0 \tag{2}$$

properties for any codeword hold, where $t+\tau$ is calculated by modulo n.

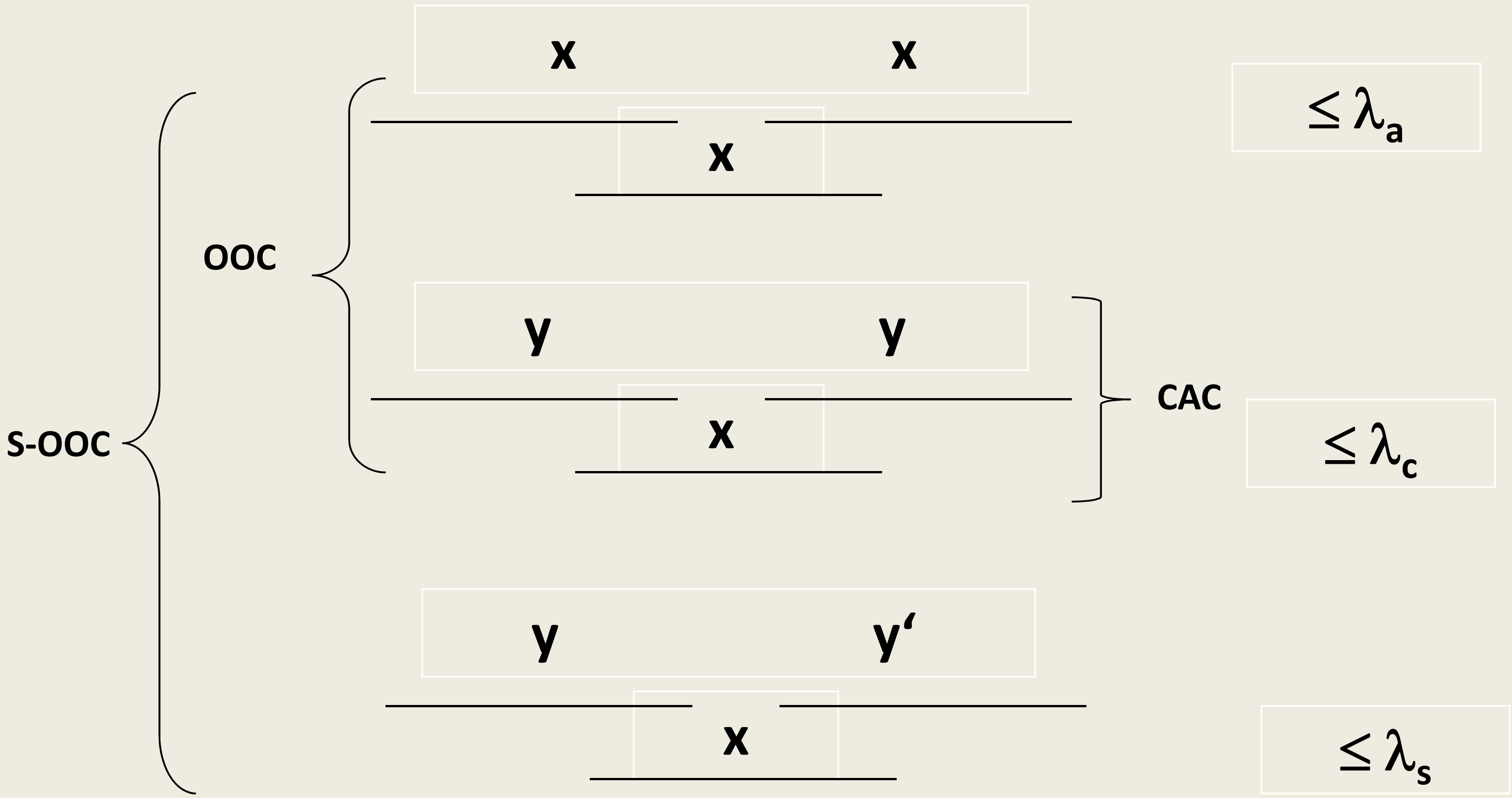
Example of an OOC of length 7, w = 2, λ = 1

$$C = \begin{matrix} 1100000 \\ 1010000 \\ 1001000 \end{matrix} \qquad \begin{matrix} \Delta_1 = \{1,6\} \\ \Delta_2 = \{2,5\} \\ \Delta_3 = \{3,4\} \end{matrix}$$

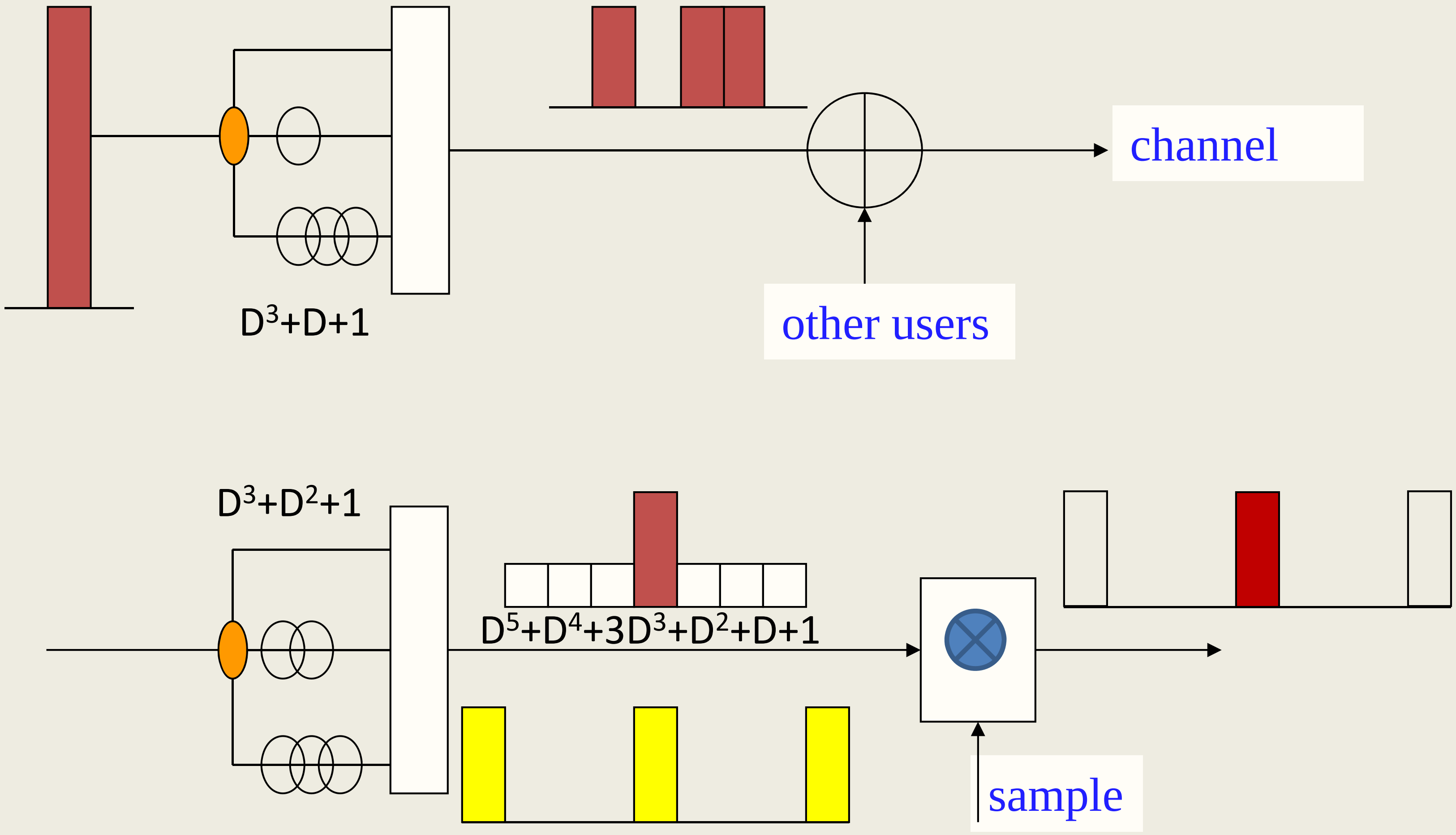
There are more interesting variations on the correlation conditions

(no time, sorry)

Illustration of different condition selections



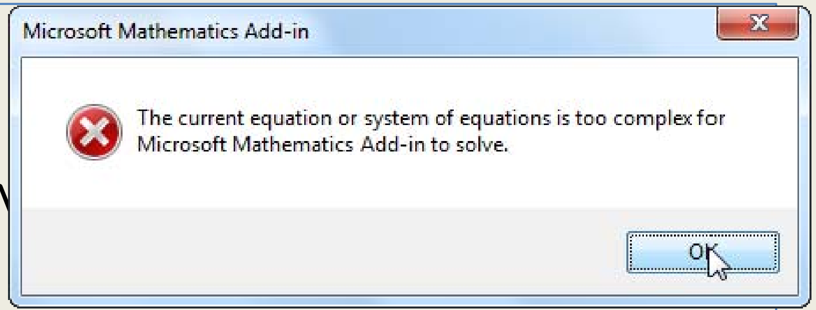
An ALL Optical transmitter/receiver pair



There are several different constructions

Mathematical design solutions:

- projective geometry (Chung, Salehi, Wei,
- balanced incomplete block designs (R.N.M
- difference sets (Jungnickel)



Japanese implementation reference: Tomoaki Ohtsuki (Univ. of Tokyo)

We used difference sets to construct codes for which:

(n, w, 1) $\quad |OOC| \geq \frac{n}{w(w-1)^2}$

(n, 4, 2) $\quad \frac{n^2}{24} \geq |OOC| \geq \frac{n^2-2n-8}{36}$

Optical Orthogonal Code Construction with Correlation 2, S. Martirosyan, Sosina Martirosyan, A.J. Han Vinck, the 23rd Symposium on Information Theory and its Applications (SITA 2000), Aso, Kumamoto, Japan, Oct. 10-13, 2000

A Construction for Optical Orthogonal Codes with Correlation 1, IEICE TRANSACTIONS on Fundamentals of Electronics, Communications and Computer Sciences Vol.E85-A No.1 pp.269-272, Samvel MARTIROSYAN A. J. Han VINCK

The main research questions

Construct Optical Orthogonal Codes of length n

with a maximum number of codewords

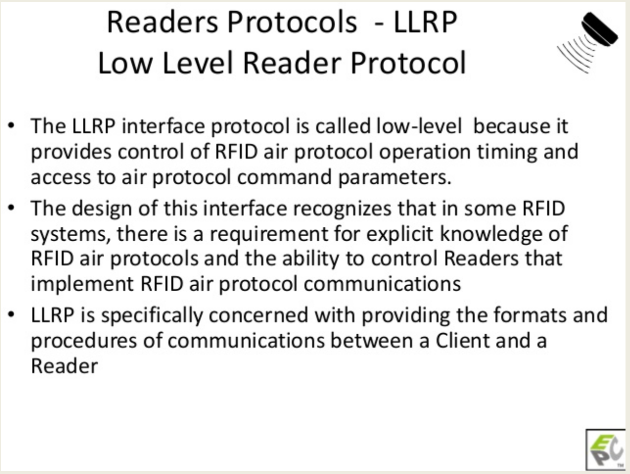
for different correlation constraints

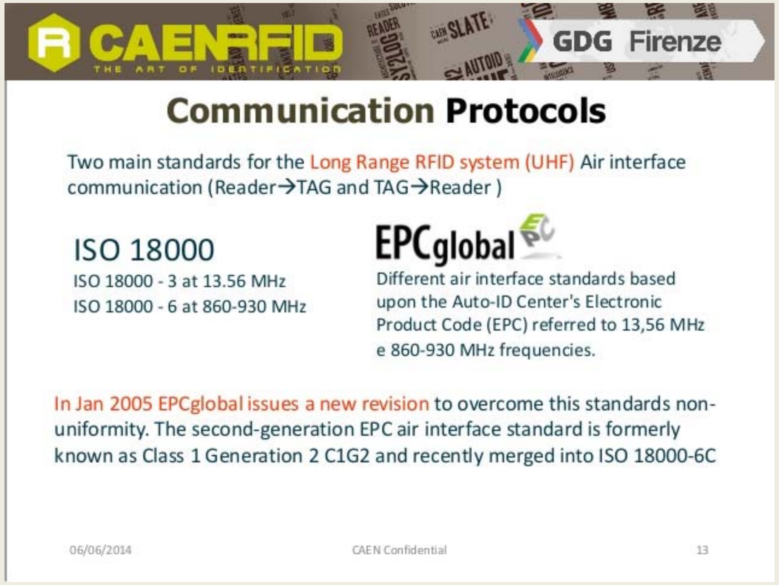
- Finding bounds on the cardinality of these codes

- Performance evaluation

Nice application in networking: *use signatures as protocol sequences*

- A protocol tells us how to behave





- It is a kind of control

Instead of symbol -1- we transmit a packet

	1100000	=>	P_1 P_1 0 0 0 0 0
C =	1010000	=>	P_2 0 P_2 0 0 0 0
	1001000	=>	P_3 0 0 P_3 0 0 0

0 P_2 0 P_2 0 0 0

P_3 0 0 P_3 0 0 0…

collision

2 protocol sequences can be used in **any shifted** position simultaneously:
1 position is always „collision free“

\# users N = 3

- unsynchronized: R = 2/7 ≈ 0.3
- synchronized: TDMA => 0.33

synchronized: 2 users can transmit collision free

User	signature
1	001 001 010
2	001 010 100
3	001 100 001
4	010 001 100
5	010 010 001
6	010 100 010
7	100 001 001
8	100 010 010
9	100 100 100
10	000 000 111
11	000 111 000
12	111 000 000

R = 2/9 # users N = 12

TDMA gives R = 2/12

Example:

011 101 101 = x OR y ?

ln2/T ≈ 1/3

Friendship and cooperation in science is very important

- Who are these old guys?

Toby Berger (Cornell)
Me (UDE)
Daniel Costello (Notre Dame)
Sergio Verdu (Princeton)

What did we discuss?

- We <u>pointed</u> at a few interesting areas, where engineers, computer science and mathematics go together well!

- <u>Topics:</u>
  - capacity of or-channel communication
    - (coordinated and un-coordinated
  - codes (still many problems to be solved!)
    - (synchronized and un-synchronized)