SAPIENZA
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IoT: lecture 4

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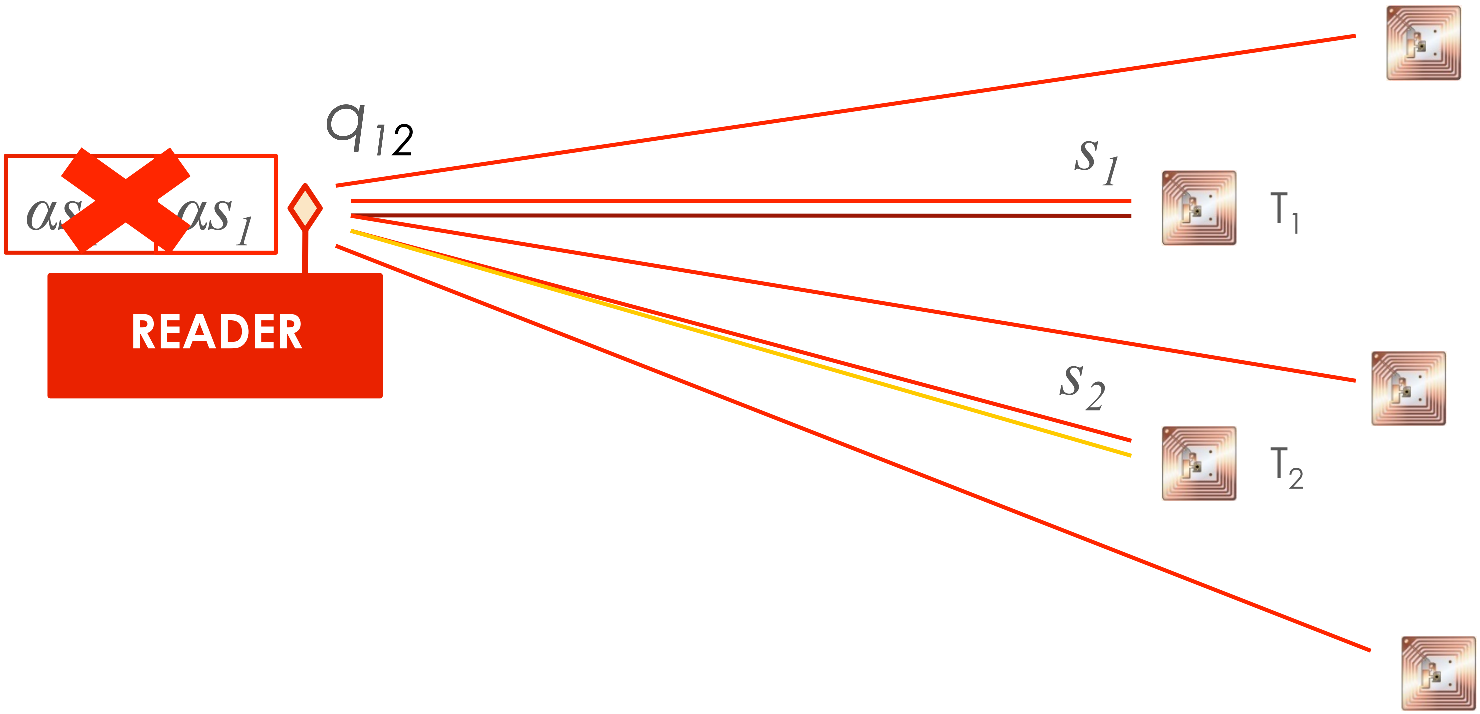
Concurrent protocols for tag identification

Sequential vs. concurrent

- Tag identification has originally been addressed as an anti-collision (or arbitration) problem.
- Aloha-based and tree-based protocols aim at avoiding collisions in order to **sequentially** read tags.
- A recent trend is to use a different approach to tag identification: **exploiting collisions** instead of avoiding them

Tag collisions

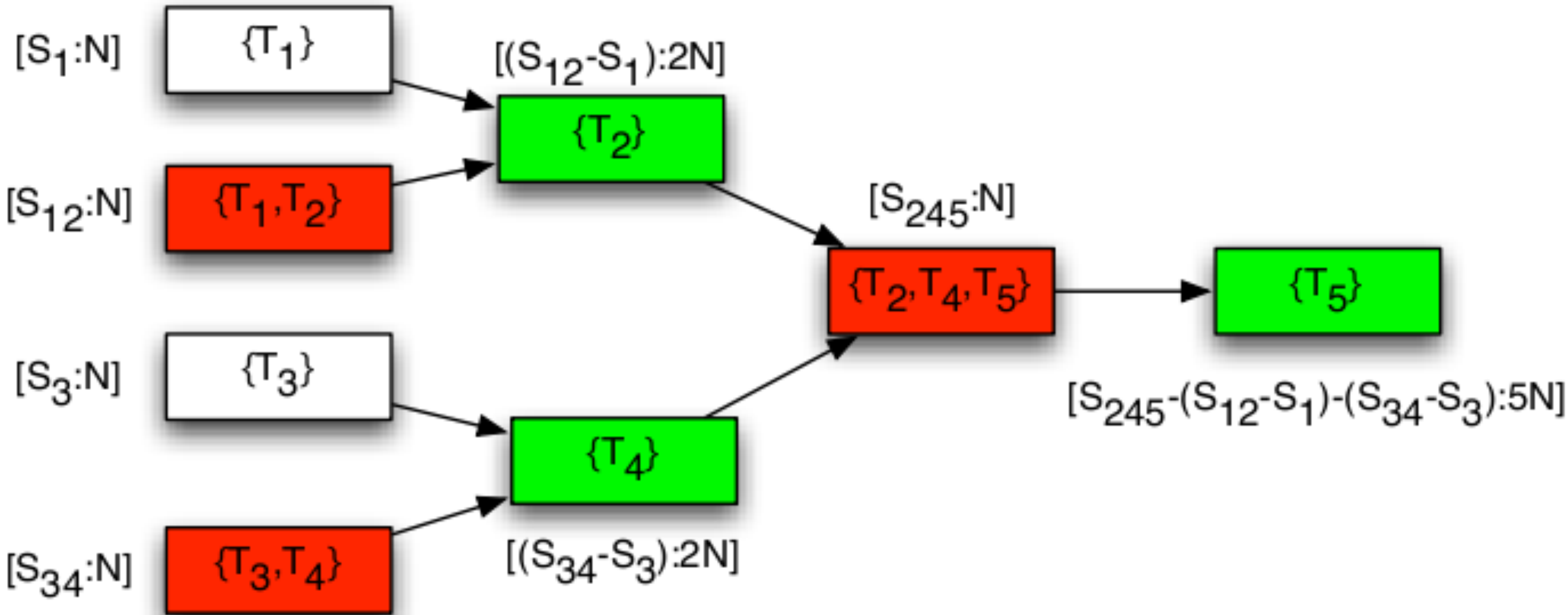


Interference cancellation-based RFID Tags Identification

Interference cancellation

- Performance evaluation of sequential protocols shows that almost 50% of the identification time is wasted in collisions.
- Proposal: **to use interference cancellation (IC) to utilize the signal of collision**s to improve the tag identification rate.
- Interference cancellation in this work is based on **difference of signals from different transmissions**.

Interference cancellation: example



Interference cancellation

- When a tag transmits its ID, each antenna receives a signal dependent on particular amplitude and phase, which are related to several factors such as the reader transmission power, the relative location and orientation of the tag to the reader, the transmission noise level.

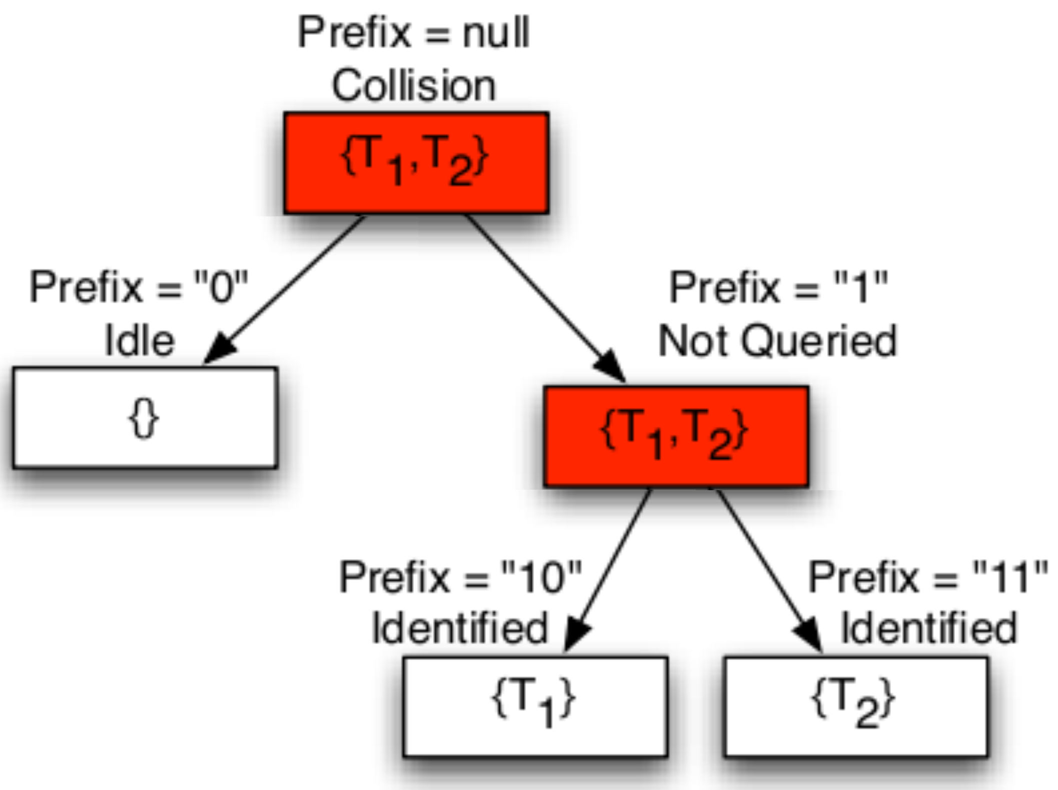
- We represent signal's amplitude and phase as a unique **attenuation coefficient** (or channel coefficient) that we assume to be constant across successive transmissions between a given couple tag reader.

$$y_i = n + h_i x_i$$

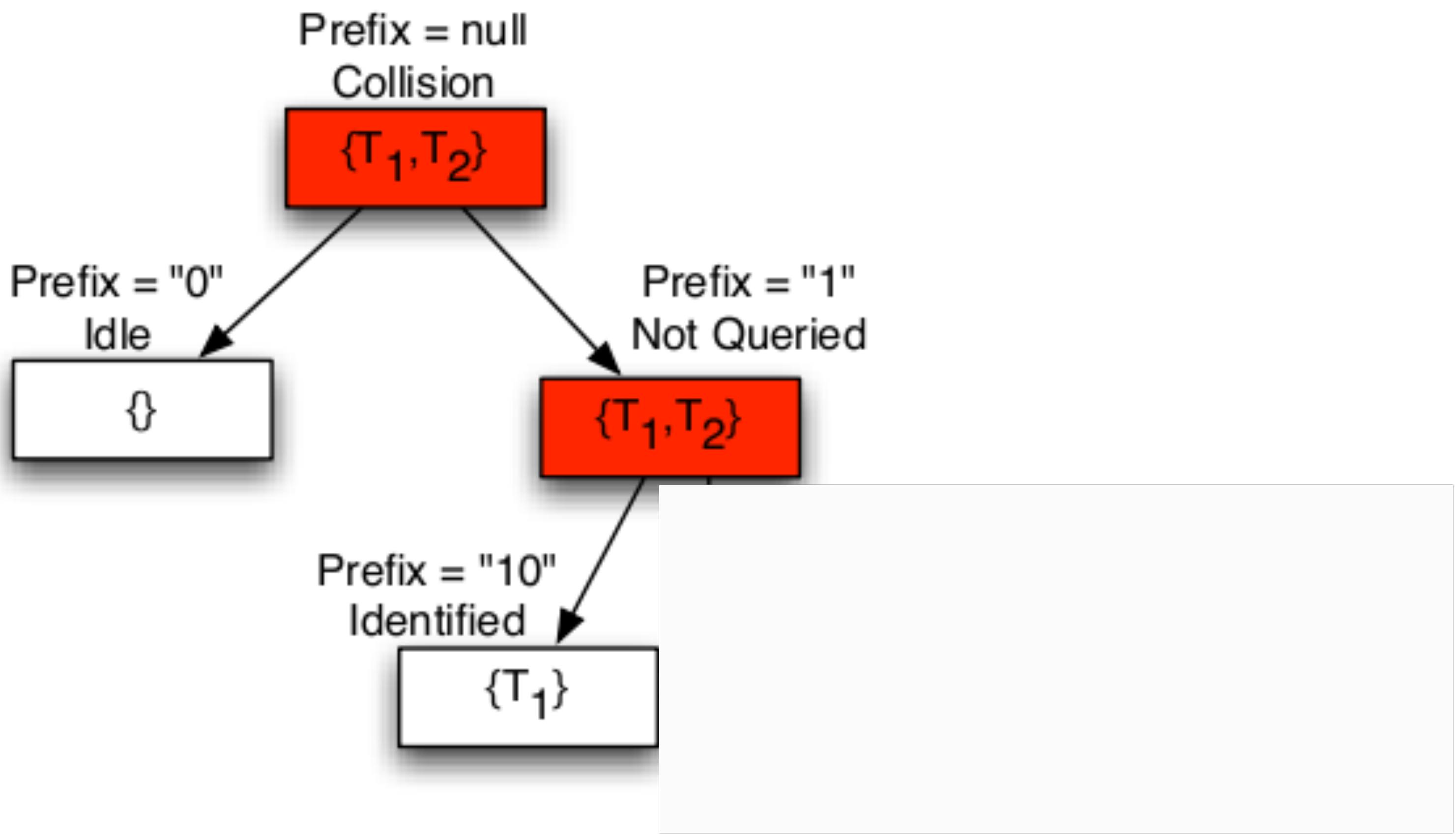
Interference cancellation

- When the difference of the signals of {T1, T2} and {T1}, referred to as residual signal, is demodulated, it may lead to tag T2 being recognized.
- The power of this residual signal is $S_{12} - S_1$.
- Its noise component is 2N since subtracting signals does not cancel noise; instead, noise components are added.
- As a result, the SNR of the residual signal is $(S_{12} - S_1) - 2N$.
- An important consequence of the increasing of noise is that the SNR of successively inferred packets using interference cancellation decreases. Since the SNR of the residual signal must be greater than or equal to the threshold, this limits the extent of the possible interference cancellation.

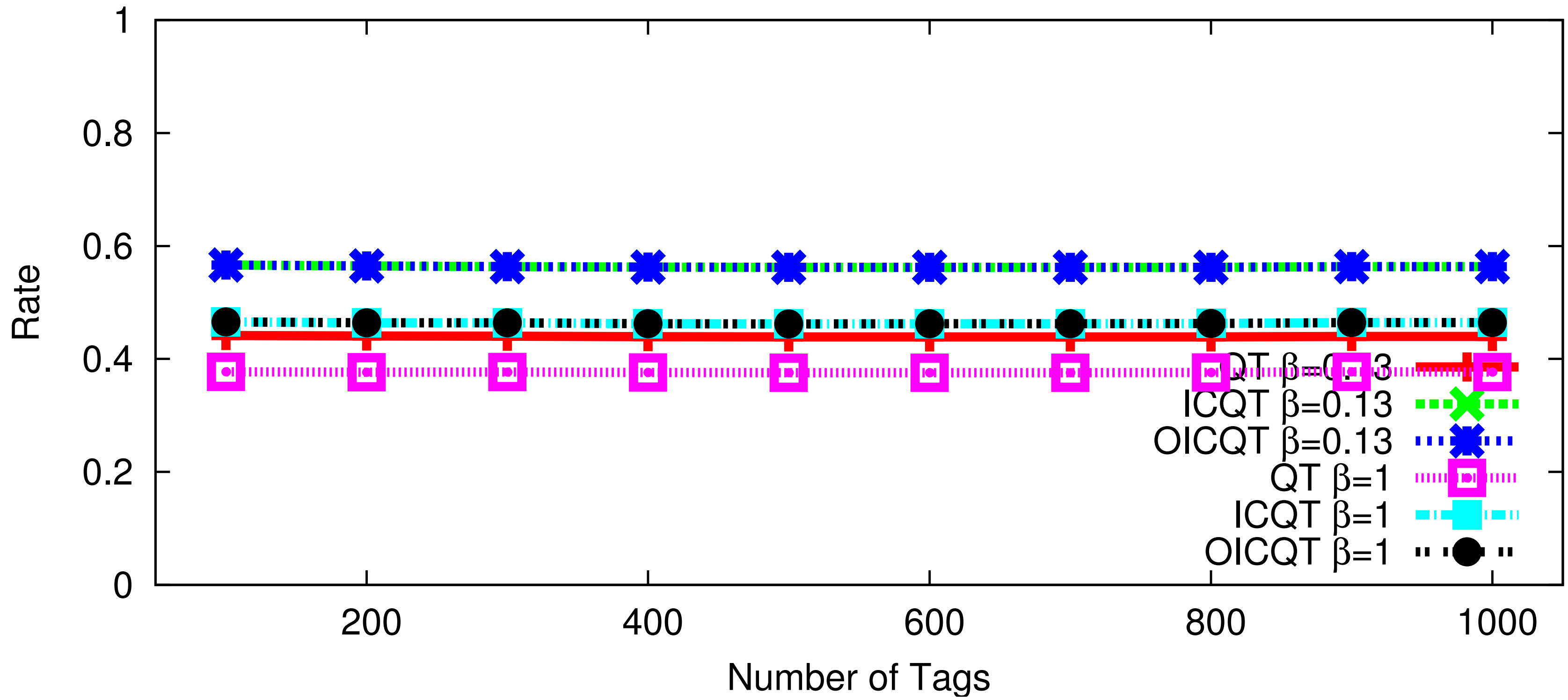
Query tree


Prefix = null
Collision
{T1,T2}
Prefix = "0"
Idle
{}
Prefix = "1"
Not Queried
{T1,T2}
Prefix = "10"
Identified
{T1}
Prefix = "11"
Identified
{T2}

Query tree with interference cancellation



Performance evaluation

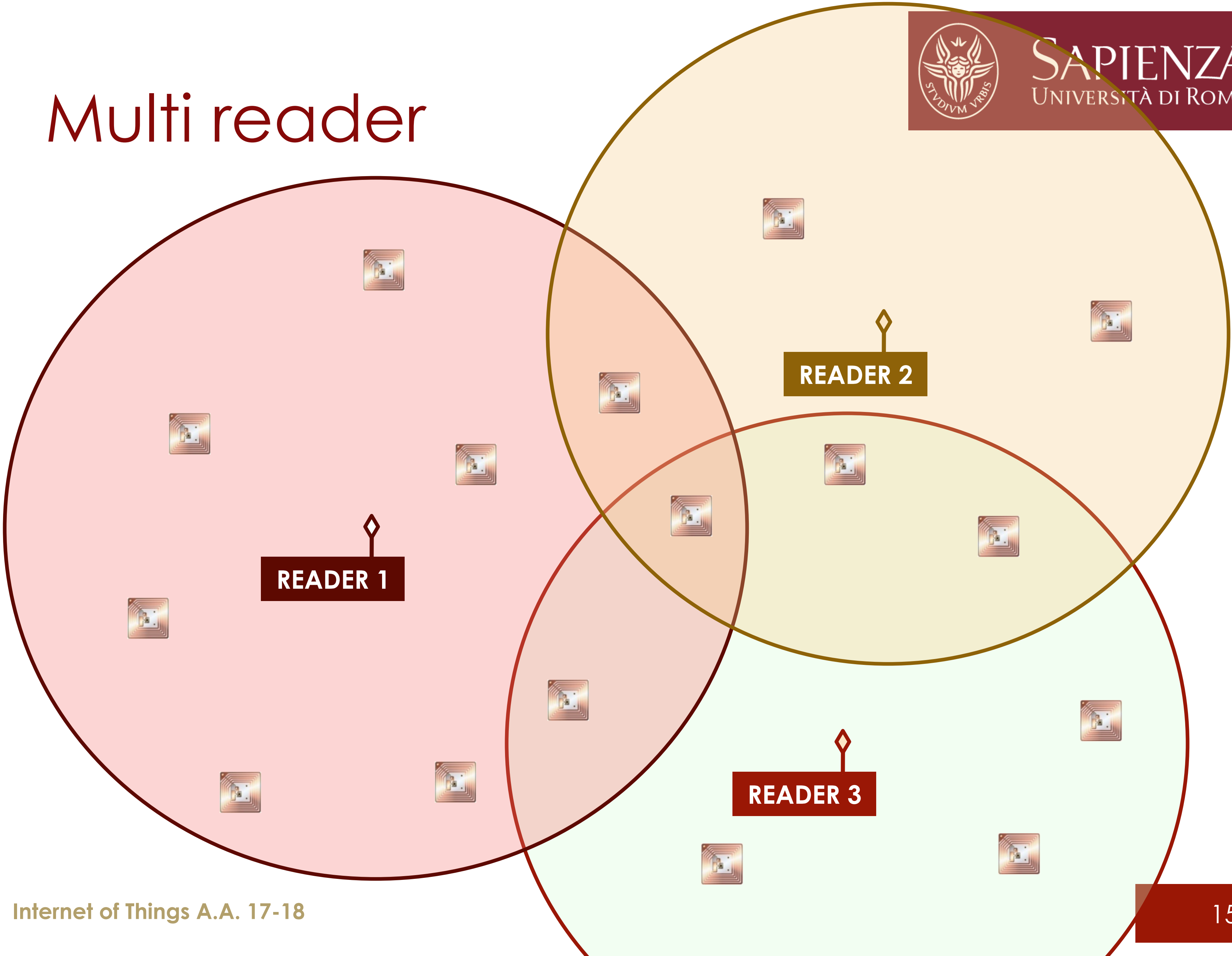


Fully concurrent solutions

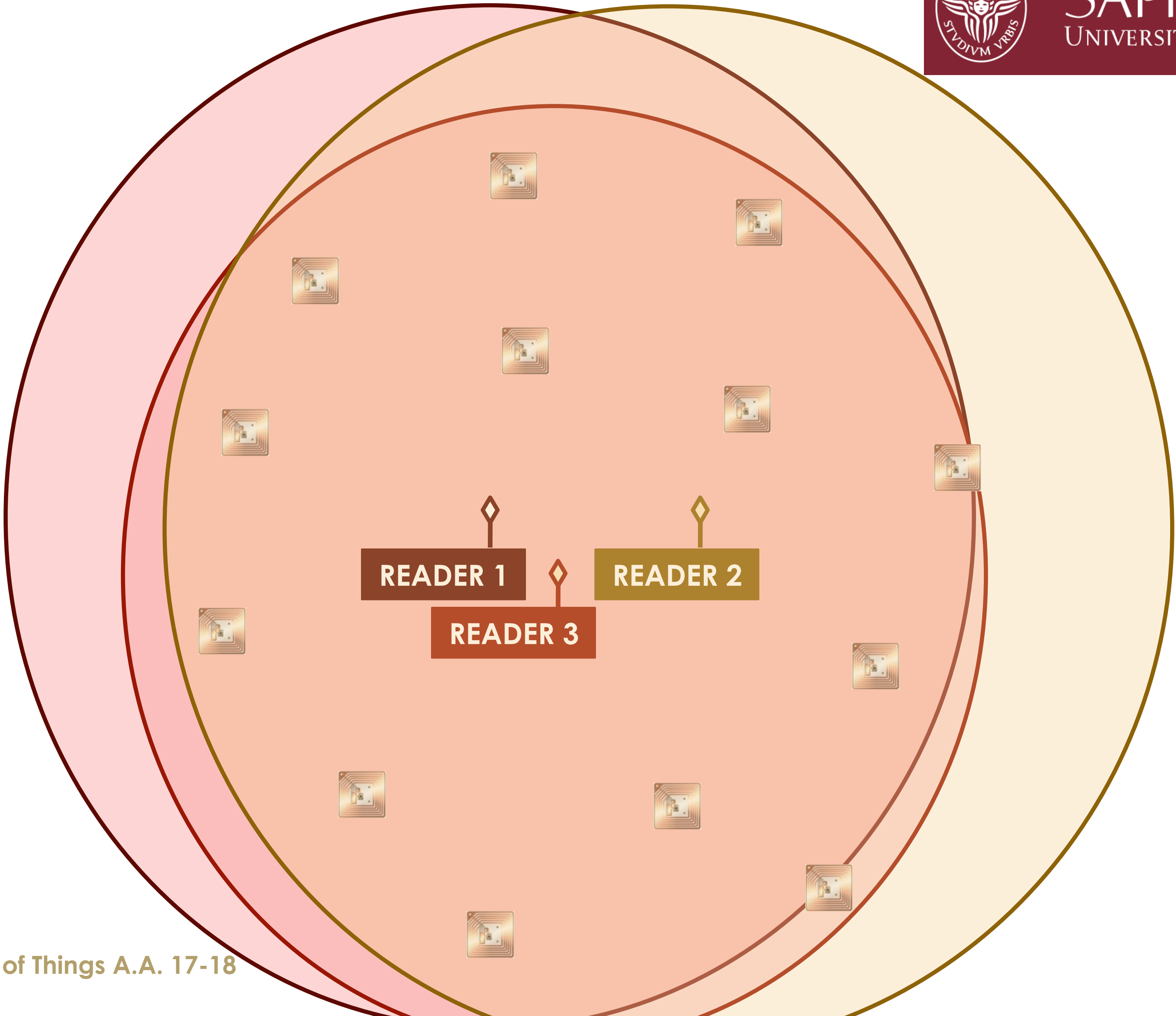
- TIANC
- BUZZ

TIANC: Tag Identification through Analog Network Coding

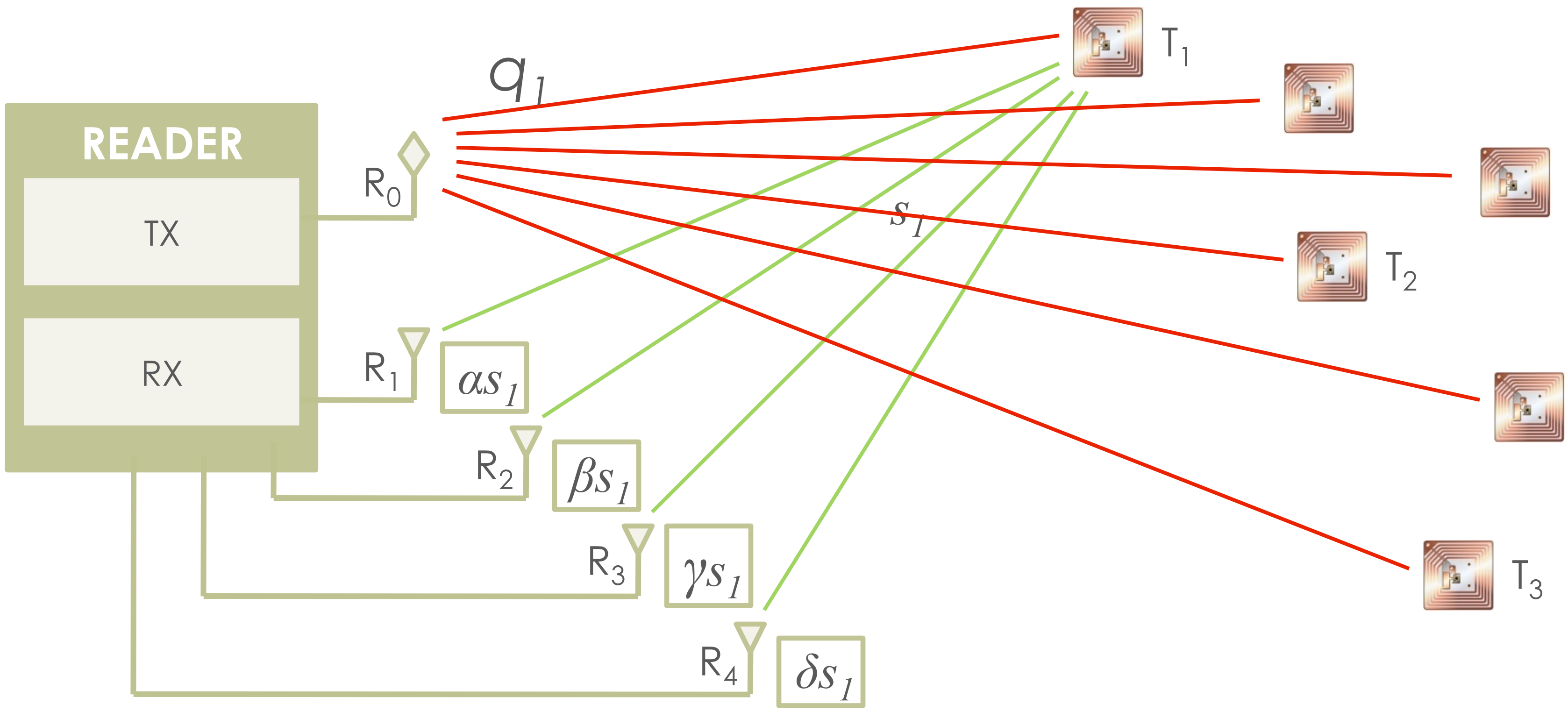
Multi reader

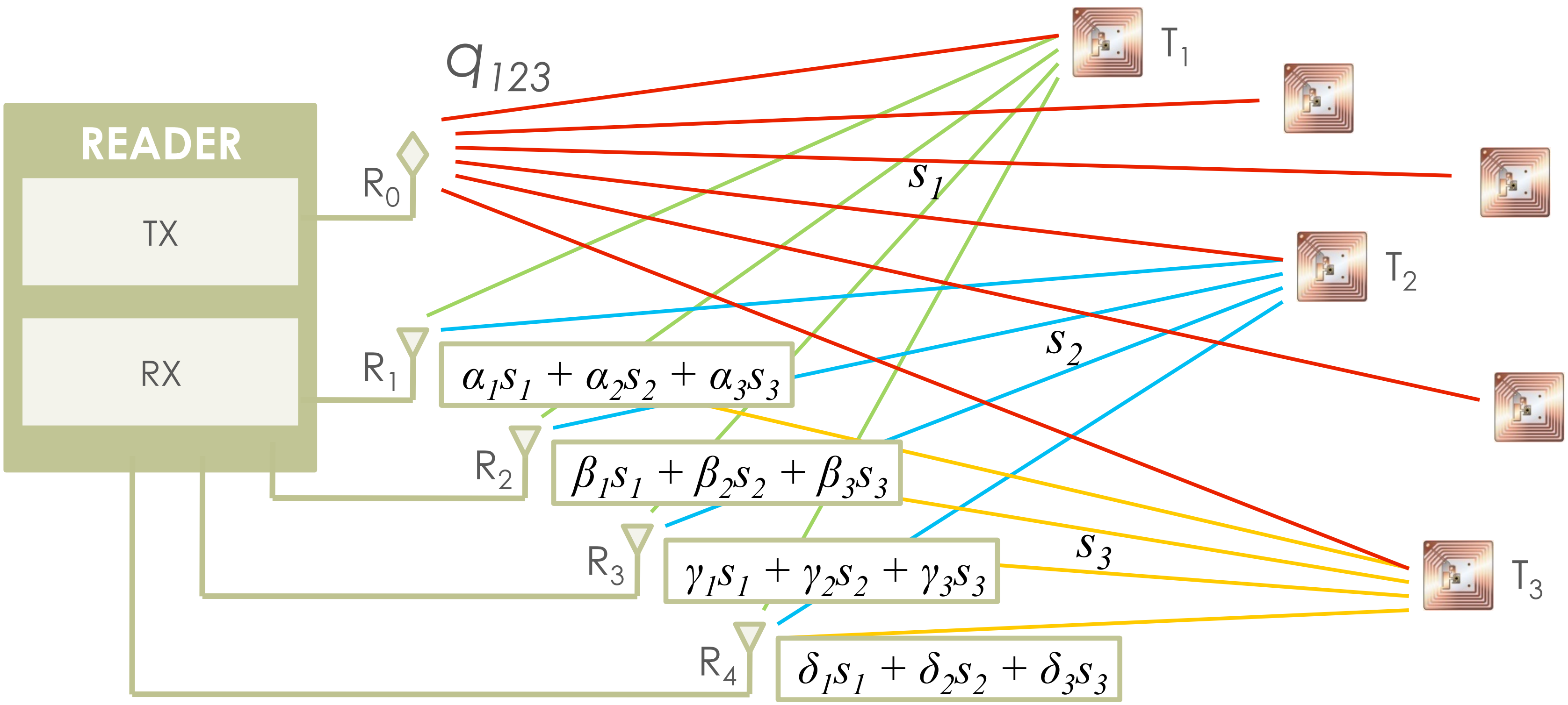


Multi reader in TIANC



Concurrent transmissions





q_{123}
READER
TX
RX
R_0
R_1
R_2
R_3
R_4
T_1
T_2
T_3
s_1
s_2
s_3
$\alpha_1 s_1 + \alpha_2 s_2 + \alpha_3 s_3$
$\beta_1 s_1 + \beta_2 s_2 + \beta_3 s_3$
$\gamma_1 s_1 + \gamma_2 s_2 + \gamma_3 s_3$
$\delta_1 s_1 + \delta_2 s_2 + \delta_3 s_3$

Analog Network Coding (ANC)

$$\begin{cases} r_1 = \alpha_1 s_1 + \alpha_2 s_2 + \ldots + \alpha_k s_k \\ r_2 = \beta_1 s_1 + \beta_2 s_2 + \ldots + \beta_k s_k \\ \vdots \\ r_r = \gamma_1 s_1 + \gamma_2 s_2 + \ldots + \gamma_k s_k \end{cases}$$

$$k \leq r$$

$$\boxed{s_1 \quad s_2 \quad \ldots \quad s_k}$$

How can we create collisions of at least *r* tags and apply ANC to decode their IDs?

TIANC protocol

- TIANC follows a Tree Slotted Aloha (TSA) scheme: for each colliding slot in a frame a new child frame is allocated. Only the tags that collided in the parent slot participate in the same child frame.
- Each frame is divided into two sub-frames, called *training* and *identification* sub-frames.
- Tags are required to transmit in both sub-frames.
- The ***training* sub-frame** has the double objective of
  - allowing the reader to estimate channel coefficients
  - grouping tags into colliding sets of an intended cardinality.
- The ***identification* sub-frame** has the goal of identifying tags by using the estimated coefficients together with ANC.

TIANC: training

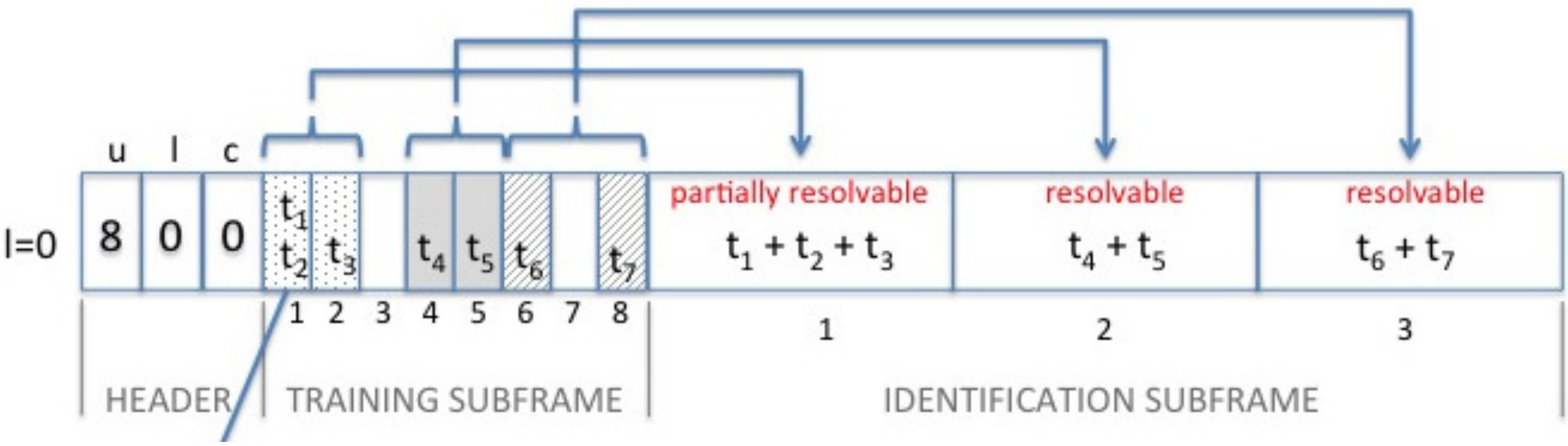
- Assumption: We know the number of tags to be identified so as to set an initial optimal size of the training sub-frame
- At the beginning of each frame, the reader sends a header specifying the values *u*, *l*, *c*, where
  - *u* is the number of slots in the training sub-frame,
  - *l* and *c* are respectively the level of the tree and the index of the collision training slot of the parent frame (if available) to which the frame refers.
  - The number of antennas *a* is communicated once for all at protocol setup.
  - The size of the identification sub-frame is not specified by the reader in the header because it is calculated during the execution of the training sub-frame.

TIANC: training

- The header is followed by the *training* sub-frame, in which tags send a "1" bit message in a randomly selected slot (in the interval [1, u]).
- Knowing the content of the message sent by tags, the reader can estimate tag attenuation coefficients and store them in a table together with the corresponding slot indexes.
- At the end of each slot in the training sub-frame the reader sends a notification regarding the slot outcome: a positive acknowledgement (ack) follows any singleton or colliding transmission slot, while a negative acknowledgment (nack) notifies an empty slot.
- Tags use notifications to find out their slot in the following identification sub-frame. The idea is to map a consecutive transmission slots of the training sub-frame (discarding empty slots) in the same slot of the identification sub-frame.
- A tag transmitting in the i-th slot of the training subframe will transmit in the j-th slot of the identification subframe, that is calculated as $j = (i - s_{idle})/a$, where s_{idle} is the number of idle slots preceding slot i.

Example with 2 antennas

7 tags
Training frame of 8 slots
2 antennas



TIANC: identification

- The *identification* sub-frame contains only colliding slots, which can be of two types: resolvable and unresolvable (or partially resolvable).

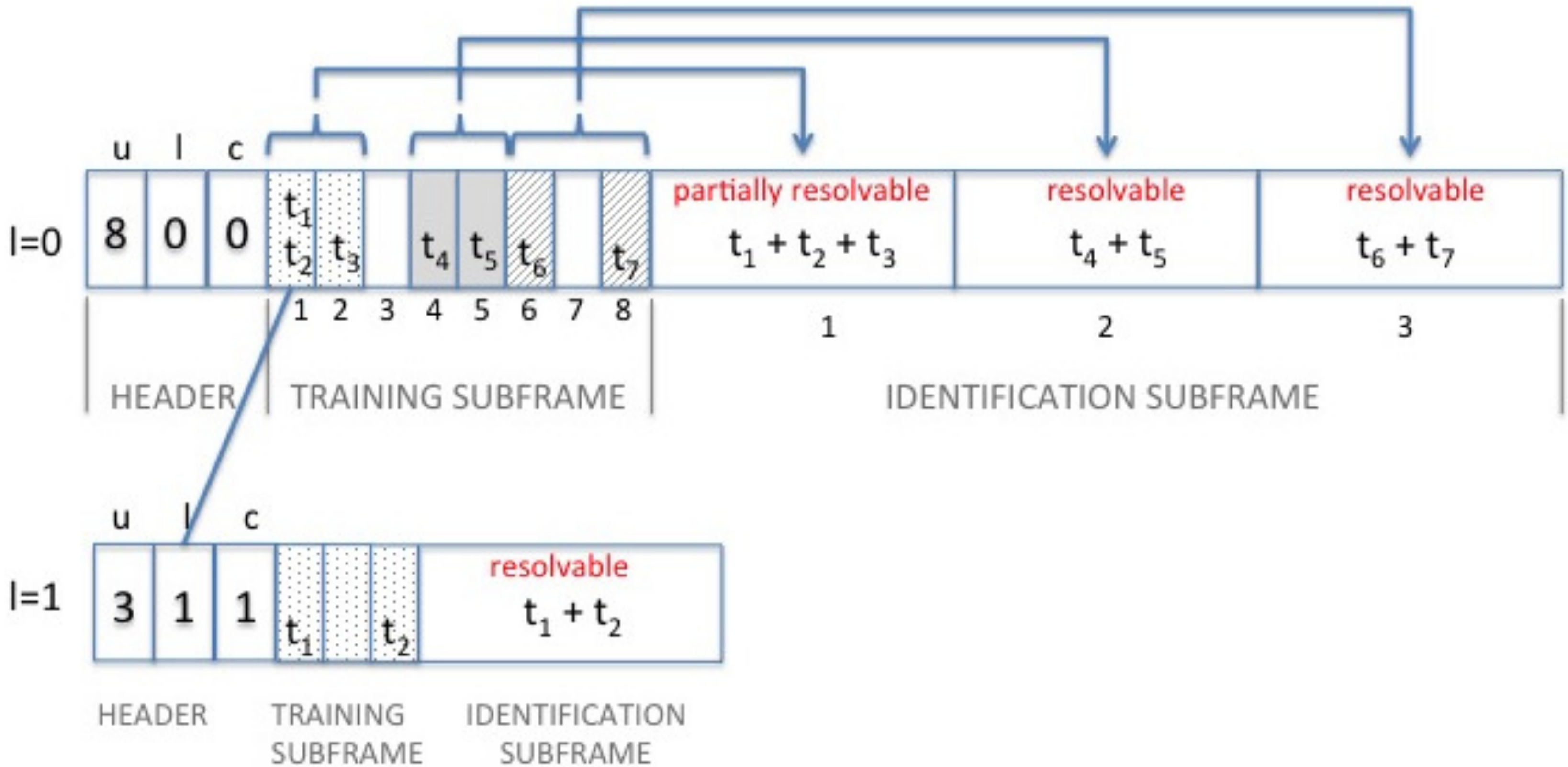
- **Resolvable slots** are characterized by the transmission of **exactly *a* tags**. Thus, each antenna receives a signal that is a combination of the *a* incoming tag signals. The reader can group these signals in a system of equations and solve it to obtain the tag IDs.

- **Unresolvable slots** feature collisions of **more than *a* tags**. In this case, the reader cannot correctly estimate all the attenuation coefficients; it can only partially solve the system and recover a number of tag IDs equal to the number of singleton training slots that are mapped to a single identification slot.

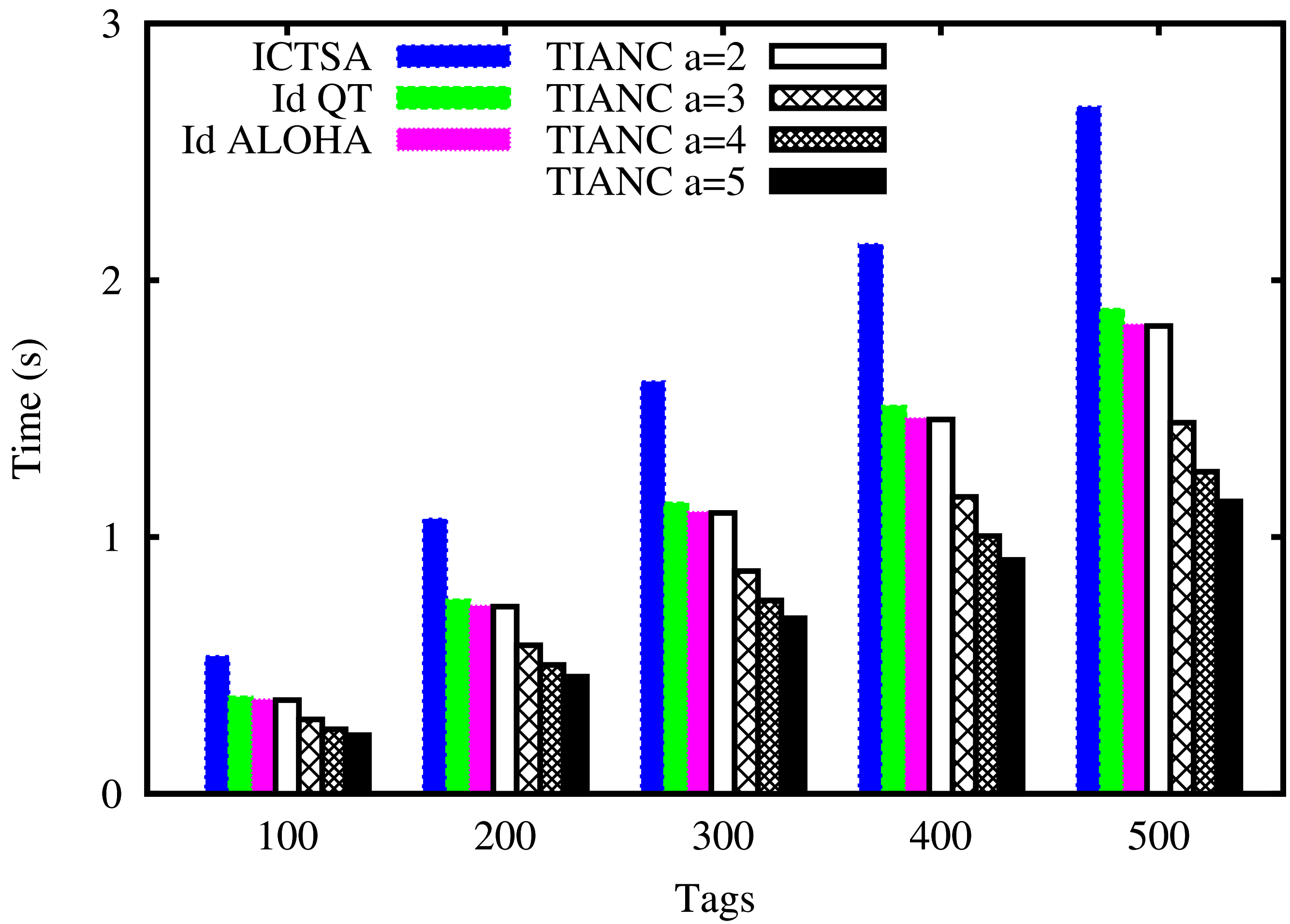
TIANC: identification

- The number of unresolvable equations gives a lower bound to the number of colliding tags. At least two tags have collided in each unresolvable equation.
- A singleton slot may correspond to an unresolvable equation due to a channel estimation error. In this case, the reader cannot correctly decode the tag ID; it interprets the transmission as a collision.
- At the end of the frame, the reader issues a new child frame for each unresolvable equation, communicating to the tags the index (c field in the header) of the training slot in the previous level to which the new frame refers (c = 1 in the example shown in Fig. 1). Only the tags that have transmitted in the c-th training slot participate into the new frame, while tags that have transmitted in other training slots and then have been mapped (translated) to resolvable equations of the same identification slot remain silent (being implicitly muted).

Example with 2 antennas



TIANC: evaluation



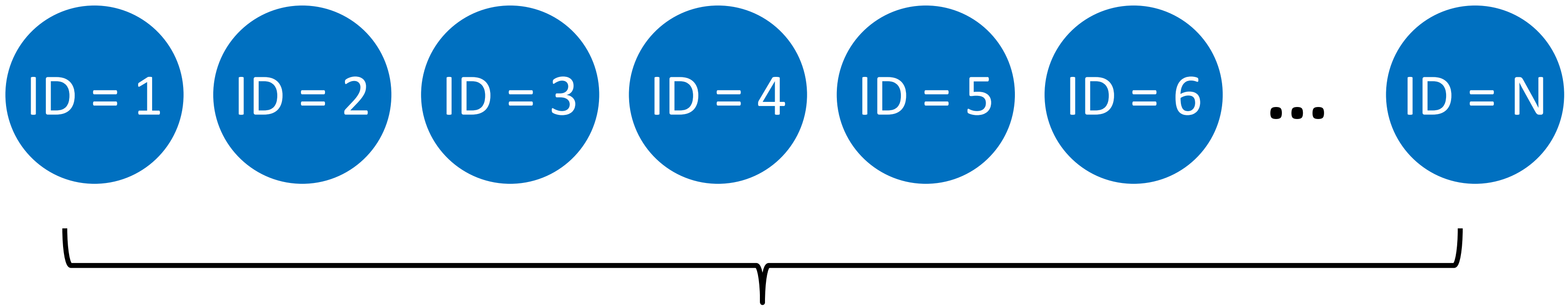
Buzz: Efficient and Reliable Low-Power Backscatter Networks

@SIGCOMM 2012

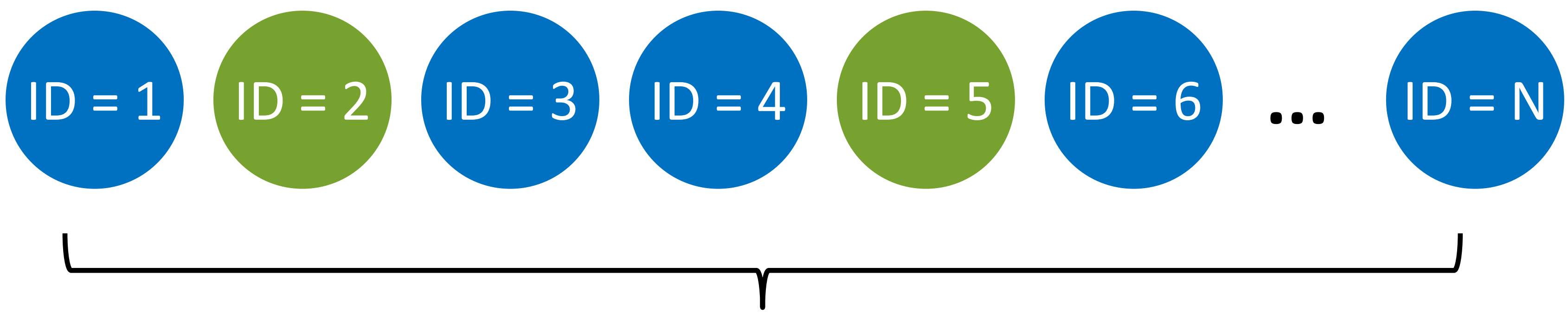
Buzz: goal

- To identify the K nodes that transmit in a network of N nodes, where K<<N
- Example: 20 items in a customer's shopping cart among one million items in a Wal-Mart store

Buzz



A million RFIDs in the Wal-Mart store



But only a few (e.g., 20) in the shopping cart

Vector x

ID = 1 ID = 2 ID = 3 ID = 4 ID = 5 ID = 6 … ID = N

System is represented by a vector $\mathbf{x}$

$x_i = 1$ if node with ID = i is in cart

0	**1**	**0**	**0**	**1**	**0**	**…**	**0**

Vector X: properties

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Vector X

0	1	0	0	1	0	…	0

X is sparse

Want the network to emulate a compressive sensing sender

Compressive sensing

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \overset{\textbf{A}}{\begin{bmatrix} 0 & 1 & 1 & & 0 \\ 1 & 0 & 0 & \cdots & 1 \\ 1 & 1 & 0 & & 0 \end{bmatrix}} \times \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix}$$

- Virtual sender sends y
- Reader decodes x using a compressive sensing decoder

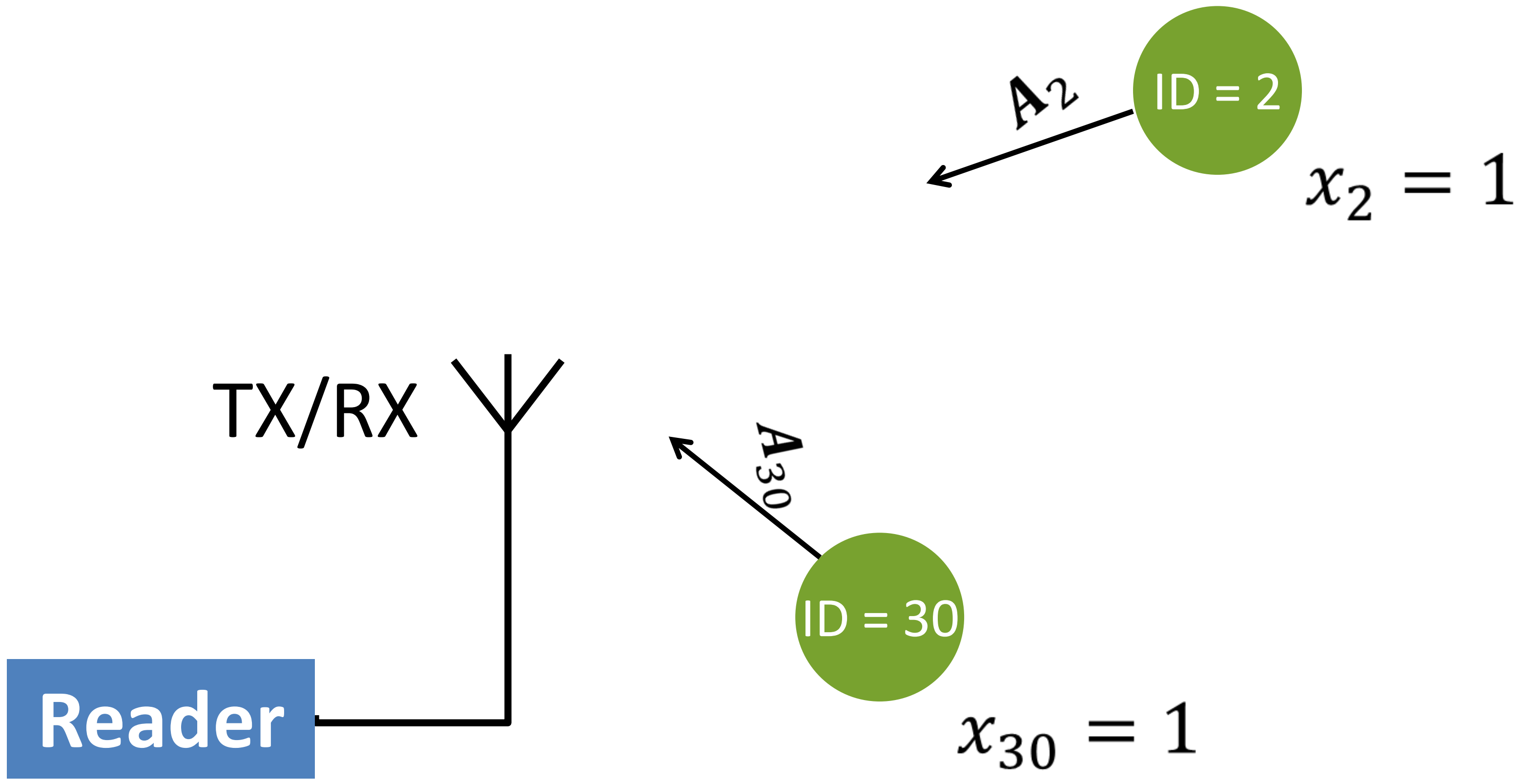
Compressive sensing

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{array}{c} \begin{array}{ccccc} \mathbf{A_1} & \mathbf{A_2} & \mathbf{A_3} & & \mathbf{A_N} \end{array} \\ \begin{bmatrix} 0 & 1 & 1 & & 0 \\ 1 & 0 & 0 & \cdots & 1 \\ 1 & 1 & 0 & & 0 \end{bmatrix} \end{array} \times \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix}$$

- Node with ID i transmits A_i

Example

- Cart has only ID 2 and ID 30



Example

- The reader receives a collision: $y = A_2 x_2 + A_{30} x_{30}$

$$y = \begin{bmatrix} A_1 & A_2 & \cdots & A_{30} & \cdots & A_N \end{bmatrix} \times \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{30} \\ \vdots \\ x_N \end{bmatrix}$$

$$y = Ax$$

Reader uses compressive sensing decoder to recover x from y

Buzz protocol

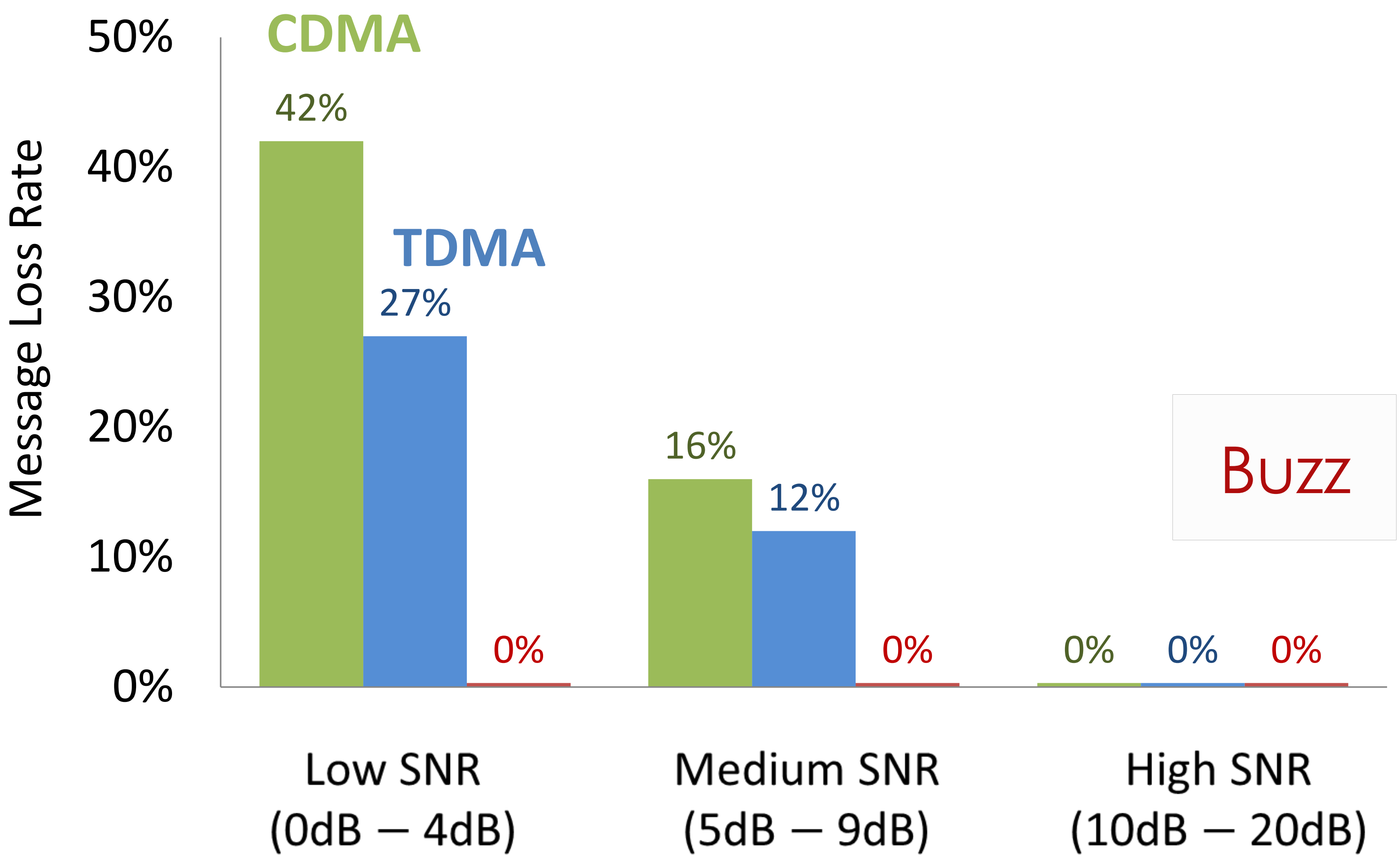
- The reader triggers the nodes to start transmitting
- Each node that has to be identified (i.e., x_i=1) then uses its id as a seed to a pseudorandom binary number generator
- For each time slot the nodes generates a random bit ("0" or "1") and transmits if the random bit is "1"
- In each time slot the reader receives one wireless symbol, which is the collision of the transmissions from a subset of the K nodes
- The nodes continue generating a random bit and transmitting it until the reader recovers the vector **x**
- When **x** is recovered, the reader triggers the nodes to stop transmitting which it can do by terminating its RF signal

Buzz time complexity

- Let *M* be the length of the binary string that each node has transmitted before the reader terminates the process
- Let A be the MxN random binary matrix where each column of A corresponds to the string transmitted by a particular node and each row of A corresponds to a time slot
- Thus $\mathbf{A}_{i,j} = 1$ if backscatter node *i* transmits in time slot *j*
- The reader receives a vector y of M symbols where each symbol is obtained in a time slot
- Since x is sparse (it has only K<<N non-zero entries), compressive sensing theory tells us that we can efficiently estimate x with a high accuracy given only

$$M \approx K \log(N/K)$$

Performance



Standard

- RFID are used in everyday life
- Standard protocol used by commercial readers:
- **EPC Gen 2 class 1** defines the physical and logical requirements for a passive-backscatter, Interrogator (RFID Gen 2 Reader) Talks First (ITF), RFID system operating in the **860 MHz ~ 960 MHz** frequency range.
- **EPC** stands for **Electronic Product Code**
- Look for the standard and try to understand its communication protocol

Readings

- R. Kumar, T.F. La Porta, G. Maselli, C. Petrioli, **Interference cancellation-based RFID tags identification**, in Proceeding of *ACM MSWIM 2011* Miami, USA.
- G. Carroccia, and G. Maselli, **Inducing collisions for Fast RFID Tag Identification,** *IEEE Communications Letters* Vol. 19, N. 10, October 2015.
- Jue Wang, Haitham Hassanieh, Dina Katabi, and Piotr Indyk, **Efficient and reliable low-power backscatter networks**, In *Proceedings of the ACM SIGCOMM 2012*.