Communication fiable et sécurisée dans des réseaux

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General context: strategic communication.

Given a communication network, find procedures allowing the players to communicate, in a way that is not manipulable by some "bad" players.

Examples: large computer networks, neural systems.

We want to design protocols (*strategies*) with good properties.

Several goals:
- how to transmit a piece of information (*reliable communication*)
- how to transmit a piece of information in a secrete way (*secure, or private, communication*)
- the information to be transmitted may be exogeneous, or generated by the protocol (*protocols for fault identification*)
- how to generate a common information (*Byzantine agreement problems*)

...

Typically:

• The identities of the bad players are unknown. These players may be *curious*, *malicious*...

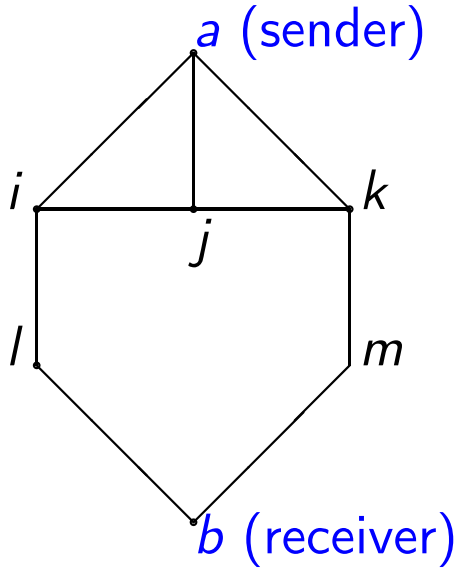
• The communication network is represented by a graph (players=nodes). The communication can be *unicast*, or *multicast*. The graph may be known or unknown.

This talk:

The communication is multicast in a known network.
Player a (the sender) knows some information $\omega \in \{\omega_1, \omega_2\}$, and wants to send ω to player b (the receiver).
At most t malicious bad players.

joint work with T. Tomala, HEC.

• a network $G = (V, E)$ (undirected graph)
- nodes: players. at each round, every player i cand send a finite message and all the neighbors of i receive this message.
- 2 particular players are fixed: a (sender) wants to send some info $\omega \in \{\omega_1, \omega_2\}$ to b (receiver).



• an integer t in $\{0, ..., |V| - 2\}$.
Some malevolent adversary may take the control of t players in $V \backslash \{a, b\}$.
Define $\mathbf{A}_t = \{T \subset V \backslash \{a, b\}, |T| \leq t\}$.

• Reliability: The communication from a to b is t-reliable if no malicious adversary controling t nodes can prevent player a to send the information to player b.

• Security: The communication from a to b is t-secure if no malicious adversary controling t nodes can prevent player a to send privately the information to player b.

References:
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Definitions:

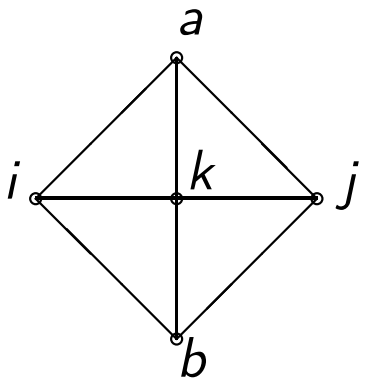
- A communication protocol π is given by:
  - a message space M (finite set),
  - a number of rounds R (positive integer),
  - a vector of behavioral strategies $\sigma = (\sigma^i)_{i \in V}$,
  - and a subset D of histories of length R for player b.

- The communication from a to b is t-reliable if for every $\varepsilon > 0$, there exists a protocol π such that: $\forall T \in \mathbf{A}_t$, $\forall \tau^T$ correlated strategy of the players in T, we have:

$$I\!P_{\omega_1,\pi,\tau^T}(D) \geq 1 - \varepsilon, \text{ and } I\!P_{\omega_2,\pi,\tau^T}(D) \leq \varepsilon.$$

Examples with $t = 1$

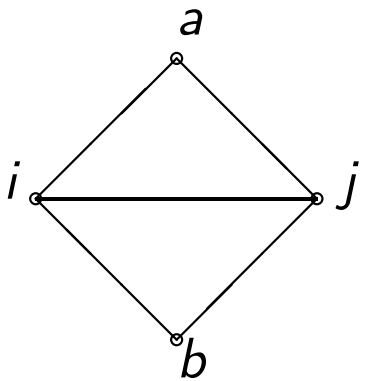
Example 1:



1-reliable

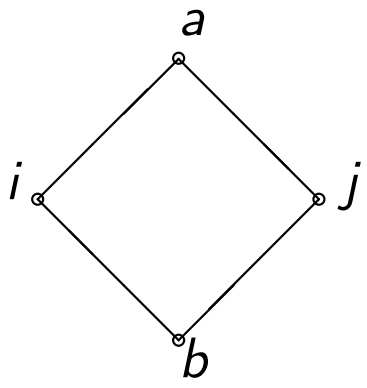
$M = \{\omega_1, \omega_2\}, R = 2$.
round 1: player a sends the true value ω_1 or ω_2.
round 2: every player i, j, k, repeats the announce of a.
$D = \{$ histories of player b where at least 2 players among i, j, k announce ω_1 at round 2$\}$.

Example 2:



not 1-reliable

Example 3:



1-reliable

Take $M = F_q$ large field.

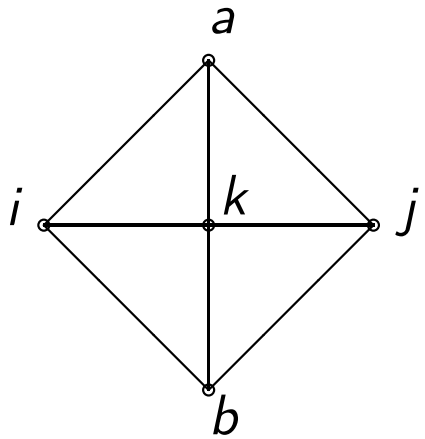
• round 1: players i (resp. j) selects m^i (resp. m^j) uniformly in M, and announces m^i (resp. m^j).
• round 2: if $\omega = \omega_1$, player a announces the sum $m^i + m^j$. if $\omega = \omega_2$, player a selects a message uniformly in M, and announces it.
• round 3: players i and j repeat the message announced at round 2 by player a.

$D = \{$ the message announced by i or by j at round 3 is $m^i + m^j\}$.
For $T = \{i\}$ or $T = \{j\}$, $I\!P_{\omega_1,\pi,\tau_T}(D) = 1$, and $I\!P_{\omega_2,\pi,\tau_T}(D) \leq 2/q$.

Theorem: Reliability, $t = 1$

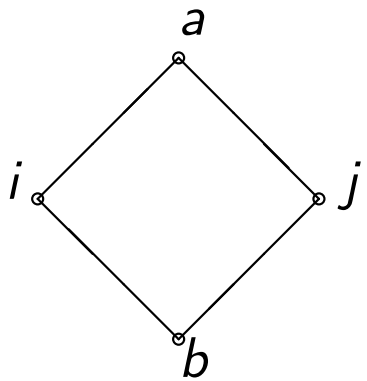
The communication from a to b is 1-reliable if and only if for every i and j in $V \backslash \{a, b\}$:

- there exists a path from a to b in $V \backslash \{i, j\}$,



or

- there exists a path from a to b not going through i, there exists a path from a to b not going through j, and i and j are not neighbours.

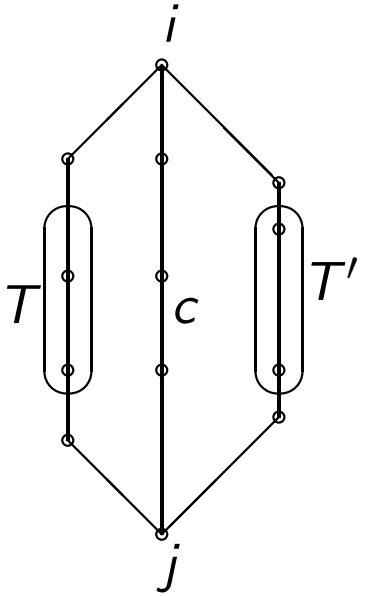


Reliability: general case

Fix T and T' in $\mathbf{A}_t$. Define a binary relation $\Gamma_{T,T'}$ on $V \backslash (T \cup T')$:

$\Gamma_{T,T'}(i,j)$ holds if:

(1) There is a path c from i to j with $c \subset V \backslash (T \cup T')$



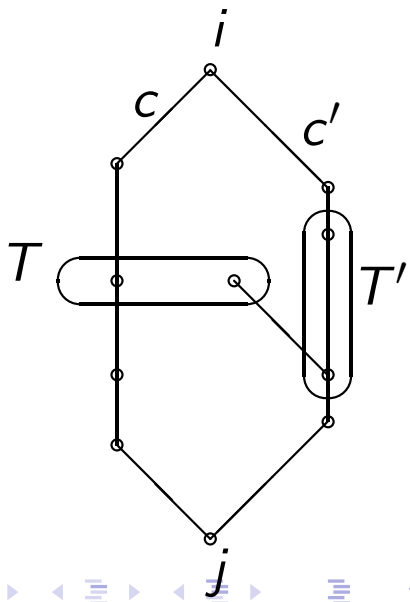
Or

(2) There is a pair of paths c, c' from i to j such that:

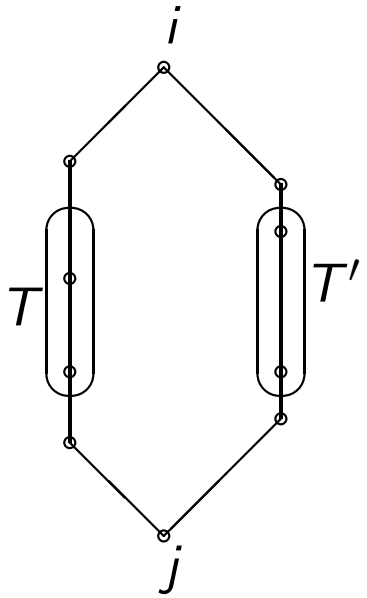
(i) $c \subset V \backslash T'$, $c' \subset V \backslash T$ and

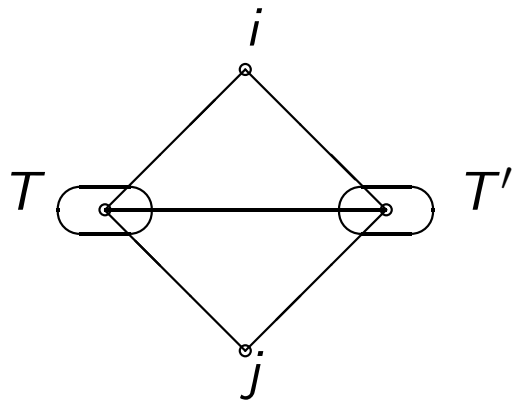
(ii) ($c \cap T$ is a singleton not seen by T')

or ($c \cap T'$ is a singleton not seen by T)



Examples without $\Gamma_{T,T'}(i,j)$:





$\Gamma_{T,T'}$ is reflexive, symetric but need not be transitive. Denote by $C_{T,T'}$ its transitive closure (associated equivalence).

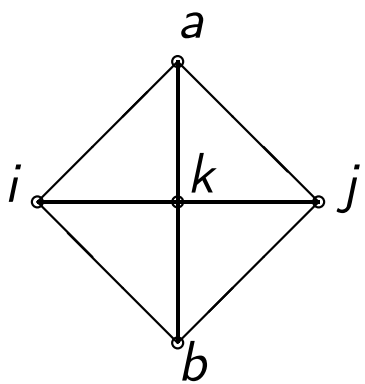
Theorem

The communication from a to b is t-reliable if and only if we have $C_{T,T'}(a,b)$ for every T, T' in $\mathbf{A}_t$.

Definition:
The communication from a to b is t-secure if for every $\varepsilon > 0$, there exists a protocol π such that: $\forall T \in \mathbf{A}_t$, $\forall \tau^T$ correlated strategy of the players in T, we have:
(i) $I\!P_{\omega_1,\pi,\tau^T}(D) \geq 1-\varepsilon$, and $I\!P_{\omega_2,\pi,\tau^T}(D) \leq \varepsilon$. (*reliability*),
and
(ii) $\|P^T_{\omega_1,\pi,\tau^T} - P^T_{\omega_2,\pi,\tau^T}\|_1 \leq \varepsilon$ (*privacy*), where P^T_{ω,π,τ^T} is the marginal distribution of P_{ω,π,τ^T} on the set of R-histories of players in T.

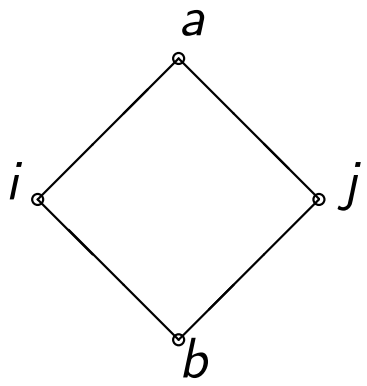
$$\textit{secure} \Longrightarrow \textit{reliable}$$

Example 1:



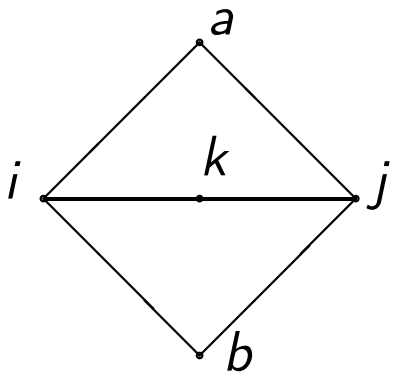
1-reliable, but not 1-secure

Example 3:



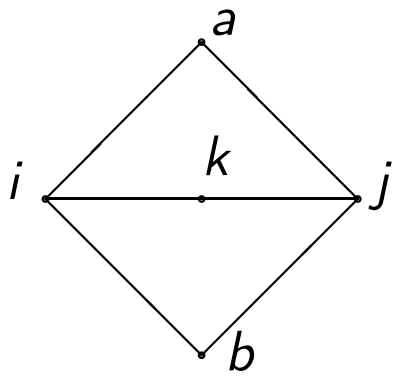
1-reliable and 1-secure

Example 4:



Can player a send
a private message to player b ?

Yes ! 1-secure.



Sketch of Proof: $M = F_q$ large field. $V := \{i, j, k\}$ set of possible adversaries.

Sub-protocol $\{l\}$, for l in V: player a sends a message $m^l \in M$ to player b, keeping it secret from l.
example for $l = k$.
round 1: a selects and announces m^a uniformly in M, whereas b selects and announces m^b uniformly in M.
round 2: j announces $m^a + m^b$
Player b can then compute $(m^a + m^b) - m^b = m^a$, player k can not.

but this can be manipulated by player j.

A reliable and private protocol:

(1) for every l in V, player a selects a message $m_l^a = (c_l^a, d_l^a)$ uniformly in M^2, and sends it to b, *keeping it secret from* l. $m_l^b = (c_l^b, d_l^b)$ received by b.

(2) for every l in V, b selects r_l uniformly in M, compute $s_l = c_l^b r_l + d_l^b$, and sends r_l and s_l *in a reliable way* to a.

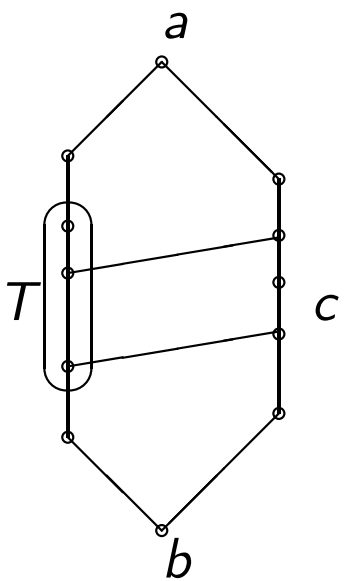
(3) a computes and announces to b *in a reliable way*:
$W = \{l \in V, s_l = c_l^a r_l + d_l^a\}$, and $z = \omega + \sum_{l \in W} c_l^a$.

$$\text{Finally, } b \text{ computes } \hat{\omega} = z - \sum_{l \in W} c_l^b.$$

Idea: suppose that j is deviating in a way such that $m_k^a \neq m_k^b$, and $m_i^a = m_i^b$.
Then $m_j^a = m_j^b$, and with high proba $W = \{i, j\}$, and $z = \omega + c_i^a + c_j^a$.
$c_l^a = c_l^b$ for l in W, so $\omega = \hat{\omega}$, player b gets the info.
j knows at most $z = \omega + c_i^a + c_j^a$ and c_i^a, but not c_j^a.

Theorem

The communication from a to b is t-secure if and only if:
1) it is t-reliable, and
2) for each T in $\mathbf{A}_t$, there is a path c from a to b in $V \setminus T$ such that T has no consecutive neighbors in c .



Remarks:

- the proof generalizes to the case when the set of bad players belongs to a given family.
- unicast communication: seems to decrease the reliability and security here.
- directed graphs: open, even for $t = 1$.
- what if the graph is unknown ?
- efficiency regarding the number of rounds, minimal graphs ?

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