# Networking through Mobile Parallel Relays[1]

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The concept

The usefulness of the concept

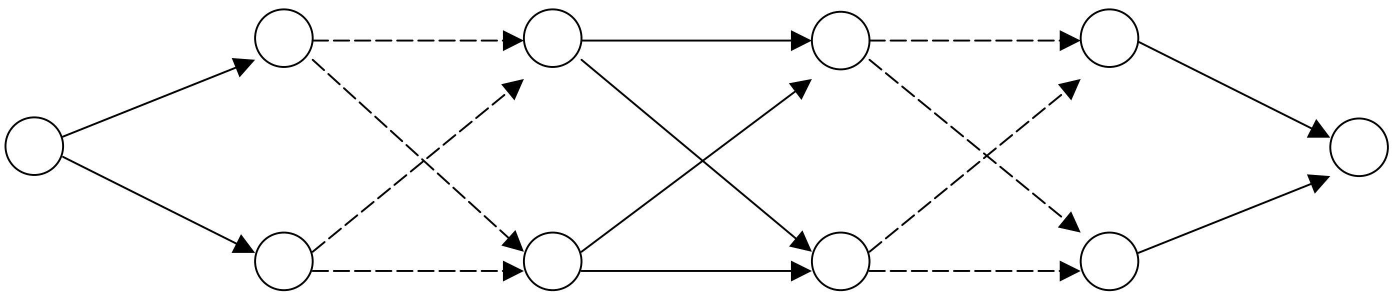
Related research activities

Some highlights of mobile parallel relays

Future research issues

[1] A presentation prepared for MURI kickoff meeting at UCSD, 15 June 2004.

## *1. The Concept*



- Each circle represents a node;
- Each arrow represents the direction of a signal flow;
- Each column may contain one, two or more nodes;
- The nodes in each column are relatively clustered together;
- Each column transmits information in parallel (cooperatively) to the next column.

## *2. The Usefulness of the Concept*

- Increased robustness against fading, shadowing, and failure at each node;
- Increased level of capacity, spectral efficiency, and power efficiency.
- Increased reliability for real-time data transmission.

## *3. Related Research Activities*

- Information theory of cooperative nodes:

  …, Cover-El Gamel (1979), …, Sendonaris-Erkip-Aazhang (1998), Laneman-Wornell (2001), Gastpar-Kramer-Gupta (2002), …

- Signal processing of cooperative nodes:

  …, Emamian-Kaveh (2001), Scaglione-Hong (2002), Hua-Mei-Chang (2003), Ribeiro-Cai-Giannakis (2004), …

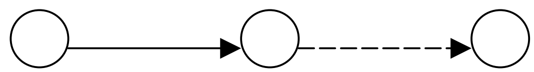
- Networking (routing) of cooperative nodes[2]:

  Hua-Chang-Mei (IEEE Workshop on DSP, 2004)

[2] Cooperative nodes defined here are those that yield an improved capacity and/or improved diversity through physical layer processing.

# *4. Some Highlights of Mobile Parallel Relays*

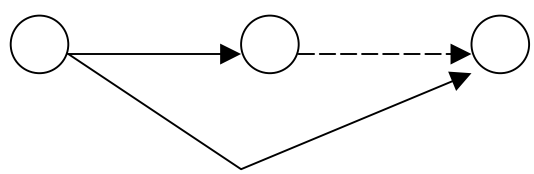
- Conventional serial relays:



$$diversity \hat{=} \lim_{SNR_a \to \infty} \frac{-\log(E(BER))}{\log SNR_a} = 1$$

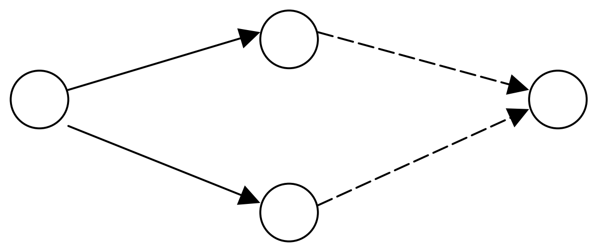
at each node

- Serial relays with source-destination cooperation:



$diversity \propto 2$ *(in theory)*
at the destination

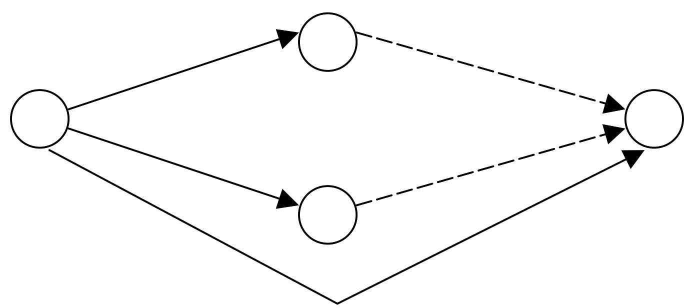
- Parallel relays (with space-time modulation):



$$diversity \propto N$$

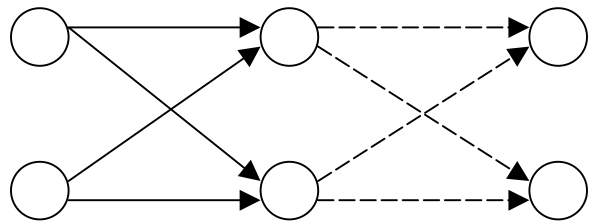
where $N$ is the number of relays

- Parallel relays with source-destination cooperation:



$$diversity \propto N + 1$$

- A chain of parallel relays:

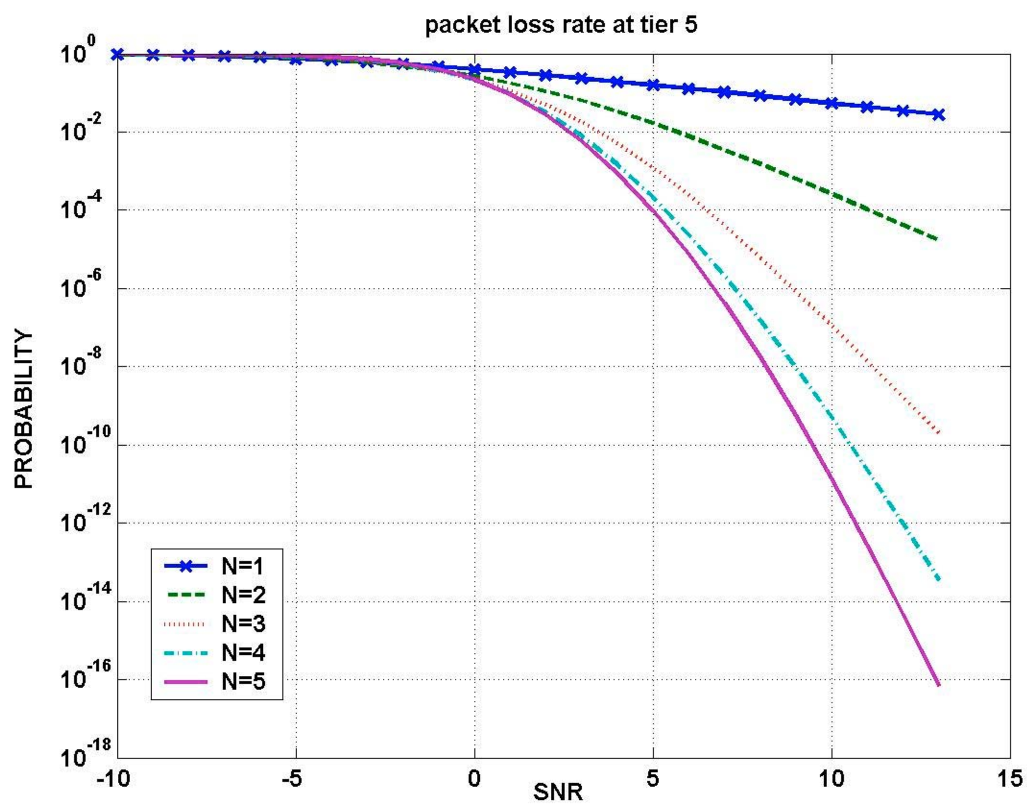


$$\textit{diversity at each node} = N$$
$$\textit{diversity at each tier} = N^2$$

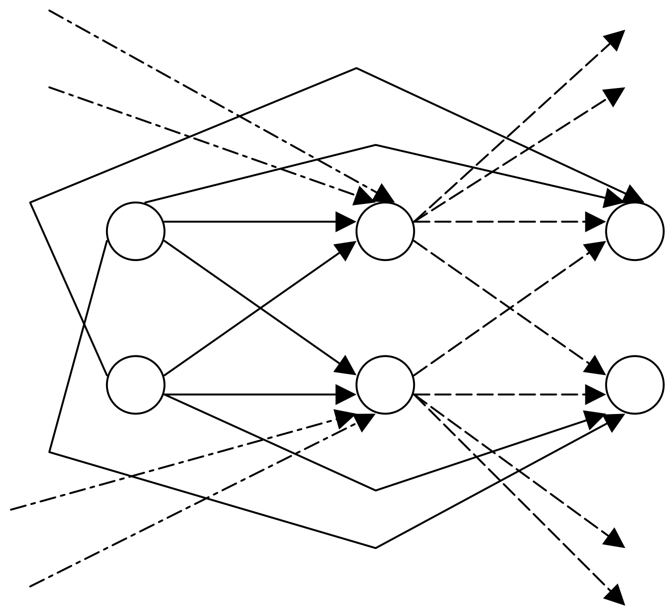
$$\frac{C_t(N)}{C_t(1)} > \frac{1-P_1^{\,N}}{1-P_1} = 1 + P_1 + P_1^{\,2} + \cdots + P_1^{\,N-1}$$

where $C_t(N)$ is the rate of correct packet transmission at tier $t$ using $N$ parallel relays, and $P_1$ is the averaged packet loss rate between one transmitter and one receiver.

- An illustration of packet loss rate of parallel relays (QPSK, orthogonal space-time block code, Rayleigh fading, Golay code for error detection and correction, the power consumed at each relay is proportional to $1/N$):



- A chain of parallel relays with signal processing cooperation of ***depth 2***:



*diversity at each node = 2N*

*diversity at each tier* = $2N^2$

***Note that for N=2, the diversity factor at each tier is 8!***

- A magic number is 2:

  - When and only when $N$=2, there are complex full-rate orthogonal space-time block codes (Alamouti-type codes);
  - These inner codes do not compromise the maximal achievable channel capacity (i.e., the optimal code for two-transmit-one-receive channels can be represented by a cascade of an optimal outer code and the Alamouti inner code);
  - When $N$>2, the system becomes much more complex and the gain becomes marginal.

- A routing algorithm of parallel relays:

  - Assume that each node knows its next-hop neighbors for a given destination *D*.
  - Step 0: Set the group (tier) index $t$=0. Since the source knows the next-hop relays for the destination, we can now assume that the group $t$ of parallel relays $R_t(1)$, $R_t(2)$, …, $R_t(N)$ all know their next-hop relays $R_{t+1}(1)$, $R_{t+1}(2)$, …, $R_{t+1}(N)$. (Note that at tier $t$=0, $N$=1.)
  - Step 1: The lead relay $R_t(1)$ requests $R_{t+1}(1)$, $R_{t+1}(2)$, …, $R_{t+1}(N)$ to provide (in order) their tables of next-hop neighbors with reference to *D*. $R_t(1)$ figures out $R_{t+2}(1)$, $R_{t+2}(2)$, …, $R_{t+2}(N)$ as the intersect of those tables, and then provides this information to $R_{t+1}(1)$, $R_{t+1}(2)$, …, $R_{t+1}(N)$.
  - Step 2: Set $t$=$t$+1. Go to Step 1.

## *5. Future Research Issues*

- Develop improved routing algorithms for mobile parallel relays;
- Analyze the cost of routing algorithms;
- Develop improved algorithms for data transmission through a route of mobile parallel relays;
- Explore the impact of mobile parallel relays on multicast and broadcast;
- Study the effects of interference on mobile parallel relays.