# A random access protocol assisted by retransmission diversity and energy reuse capabilities

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# Outline

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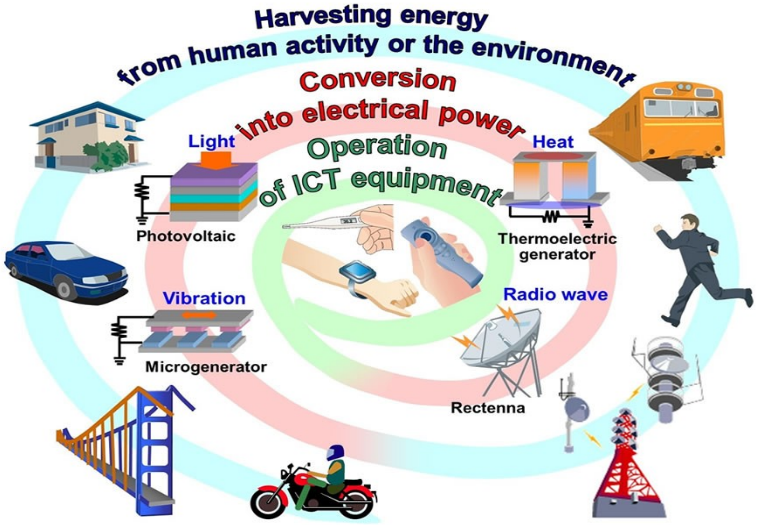
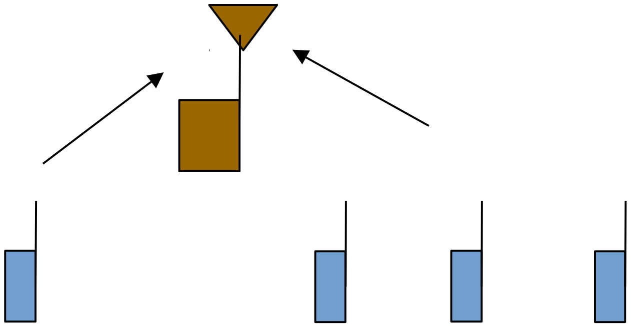
# Motivations (1)

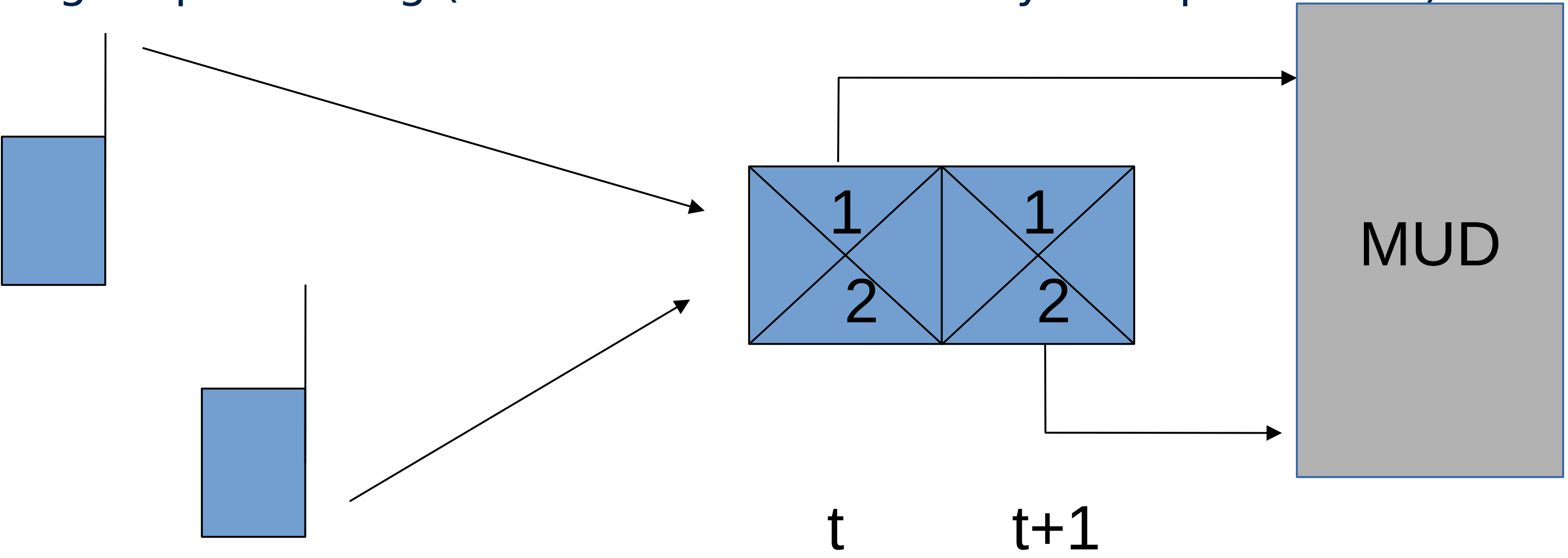
- Environmental protection concerns are leading to a **low power wireless network design and the use of “greener” energies**.
- **Wireless power transmission** and energy harvesting are two promising areas to reduce consumption,extend battery life and reduce emissions.
- WPT/energy harvesting has not been used extensively in **random access**





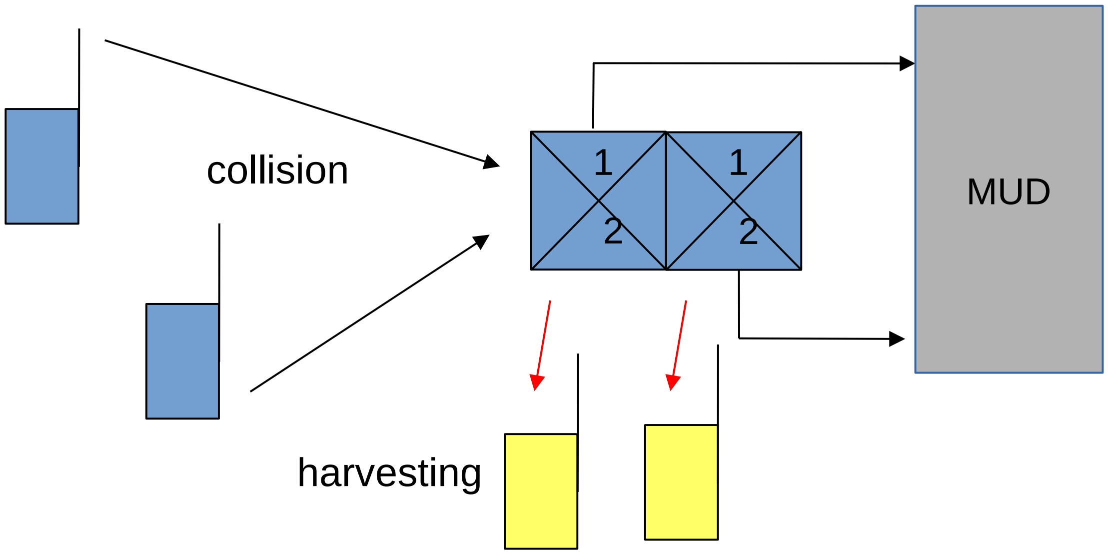
# Motivations (2)

- In random access **collisions are discarded** and throughput is lost
- This is thermodynamically inefficient as **information erasure is irreversible** and increases entropy in the system
- Therefore discarding collisions is both energetically and capacity inefficient.
- Collisions can be used by other terminals to harvest energy (WPT)
- Collisions can be controlled and used as diversity to recover information using signal processing (NDMA- network diversity multiple access)



# Operation principle

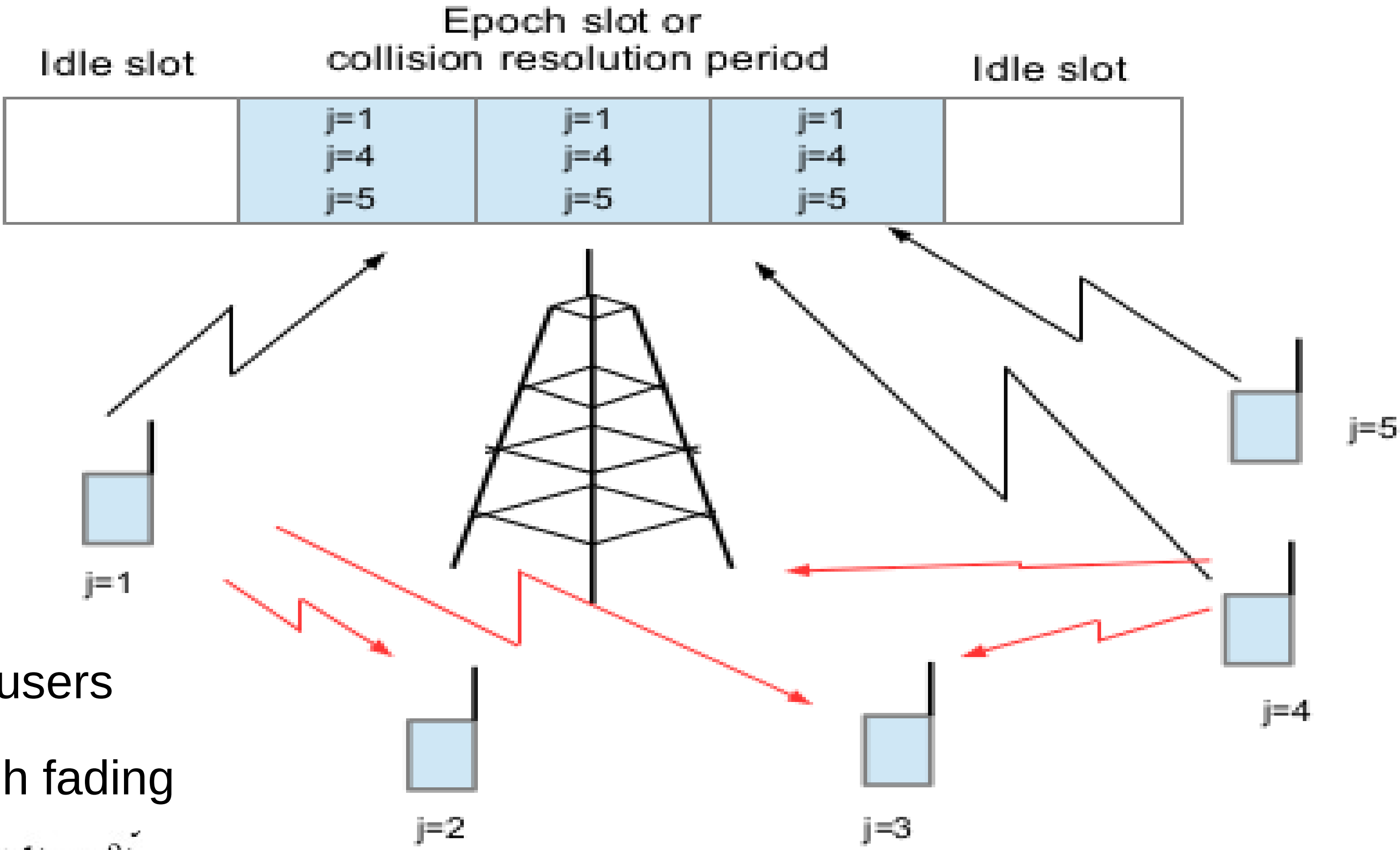
- Allow idle users to harvest energy from active terminals, particularly during collisions.
- Don discard collisions, extract information about the collision size and request more retransmissions (collisions)
- Create a MIMO channel to resolve collisions
- This means that we will combine NDMA with WPT.
- Collisions have to be controlled in order to maximize simultaneously energy harvested/reused and throughput.



# Objectives

- Study of an NDMA protocol where idle terminals collect and reuse the energy radiated by the contending terminals.
- Drive the network to a traffic load state that maximizes throughput by controlling the number of collisions below or near the allowed RD capability, and
- Control the number of collisions so that idle terminals maximize their collected energy.
- Multi-objective optimization of the throughput and the collected energy per terminal.
- Derivation of the Pareto optimal trade-off solution between throughput and collected energy.

# System model and assumptions



J=16 users

Rayleigh fading

$h_j \sim \mathcal{CN}(0, \sigma_a^2).$

Bernoulli traffic model

Tx probability: *p*

M time slots for energy harvesting

# Signal model

## Detector signal model

Orthogonal training sequence

$$\mathbf{w}_j^T \mathbf{w}_k = \begin{cases} J, & k = j \\ 0, & k \neq j \end{cases}$$

Received header signal plus noise

$$\mathbf{y}^{(h)} = \sum_{j \in \mathcal{T}} h_j \mathbf{w}_j + \mathbf{v}^{(h)},$$

Detector matched filter

$$z_j = \left| \mathbf{w}_j^T \mathbf{y}^{(h)} \right|.$$

## Contention signal model and receivers

Mixing or MIMO model

$$\mathbf{Y}_{\widehat{K} \times N} = \mathbf{A}_{\widehat{K} \times K} \mathbf{S}_{K \times N} + \mathbf{W}_{\widehat{K} \times N},$$

ZF receiver

$$\hat{\mathbf{S}} = (\hat{\mathbf{A}}^H \hat{\mathbf{A}})^{-1} \hat{\mathbf{A}}^H \mathbf{Y}$$

MMSE receiver

$$\hat{\mathbf{S}} = (\hat{\mathbf{A}}^H \hat{\mathbf{A}} + \sigma_v^2 \mathbf{I})^{-1} \hat{\mathbf{A}}^H \mathbf{Y},$$

## Energy harvesting signal model

Received signal in idle mode

$$\mathbf{r}_k(n) = \sum_{j \in \mathcal{T}(n)} h_{j,k}(n) \mathbf{x}_j(n) + \mathbf{v}_k(n), \quad k \notin \mathcal{T}(n).$$

Avergae collected energy

$$s_k(n) = E[\mathbf{r}_k(n)^H \mathbf{r}_k(n)] = \sum_{j \in \mathcal{T}(n)} P |h_{j,k}(n)|^2 + \sigma_v^2, \quad k \notin \mathcal{T}(n),$$

# Detector and energy harvesting performance

## Receiver operating characteristic

Probability of false alarm

$$P_F = \Pr\{z_j > \beta | j \notin \mathcal{T}\},$$

Rayleigh channels

$$P_F = e^{-\frac{\beta}{J\sigma_v^2}}$$

Probability of correct detection

$$P_D = \Pr\{z_j > \beta | j \in \mathcal{T}\}.$$

## Detector throughput model

$$T_{dec} = \frac{JpP_D(pP_D + \bar{p}\bar{P}_F)^{J-1}}{J(pP_D + \bar{p}P_F) + (p\bar{P}_D + \bar{p}\bar{P}_F)^J}$$

## Irrelevant resolution period

$$E[l_{ir}] = (J-1)((pP_D + \bar{p}P_F)) + (p\bar{P}_D + \bar{p}\bar{P}_F)^{J-1}.$$

## Energy harvesting performance model

Averag energy per idle period

$$S = \frac{\left(\sum_{m=1}^{M-1} m\bar{p}^m + M\sum_{m=M}^{\infty} \bar{p}^m\right) E_n[s_k(n)]E[l_{ir}]}{\sum_{m=1}^{\infty} p^m + \sum_{m=1}^{\infty} \bar{p}^m}$$

$$E_n[s_k(n)] = (J-1)pP\gamma + \sigma_v^2.$$

$$S = [(J-1)Pp\gamma + \sigma_v^2]\frac{\bar{p}^2 - \bar{p}^{M+2}}{p - 2p\bar{p} + 2p\bar{p}^2}, \quad p \neq 0.$$

# Multi-objective Optimization

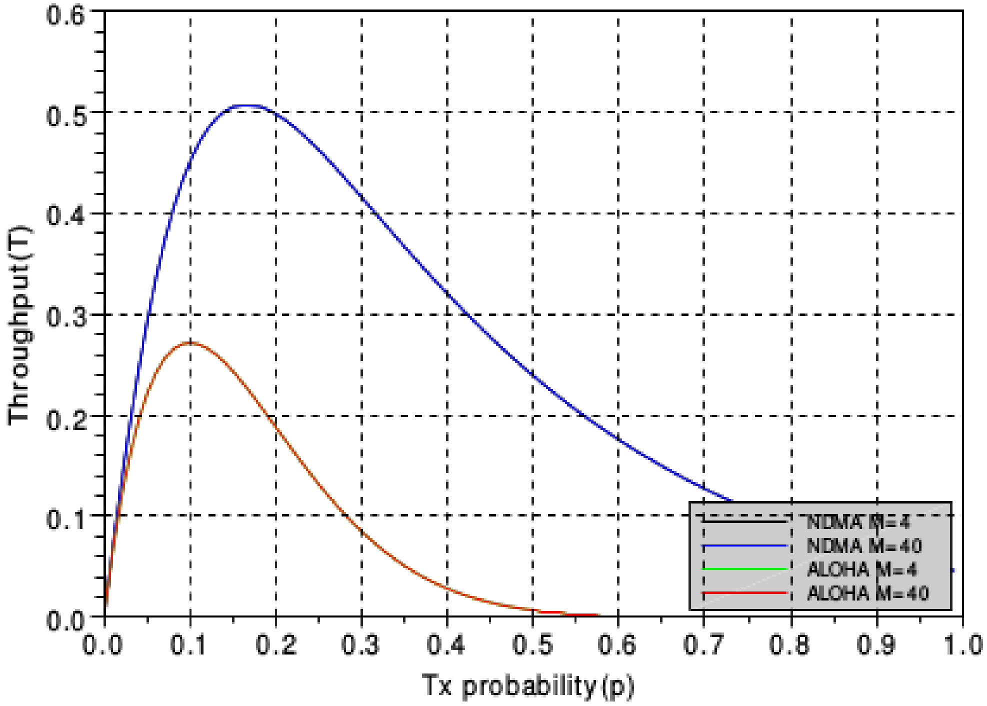
- Simultaneous optimization of throughput and collected energy

$$p_{opt} = \arg\max_{p} \begin{bmatrix} T & S \end{bmatrix}$$

- Multi-objective optimization provides with the Pareto front, which describes the best trade-off between the objective functions
- The MOO problem can be rewritten using the method of scalarization:

$$p_{opt} = \arg\max_{p} \quad f = T + \mu S, \quad \mu > 0$$

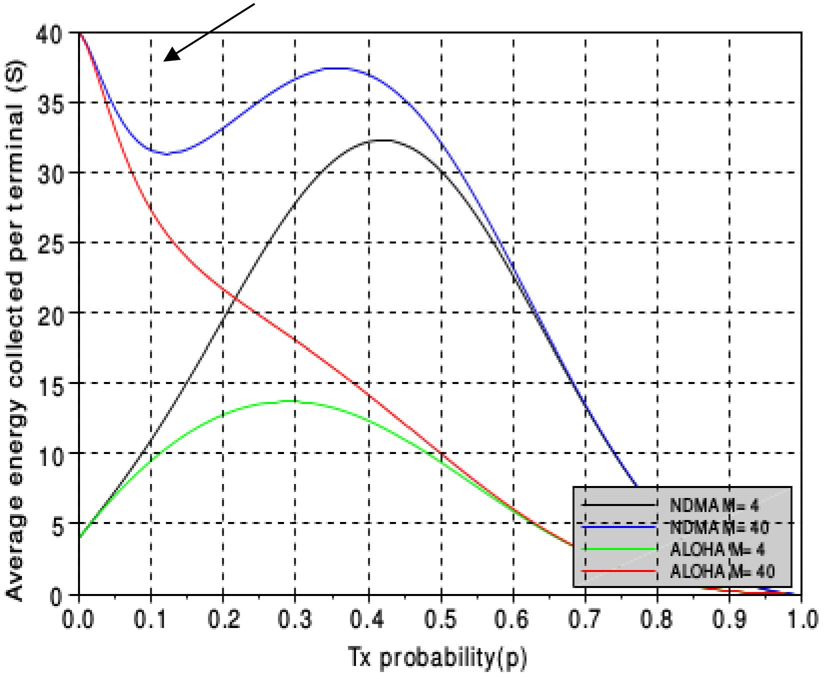
# Results



## ALOHA vs NDMA

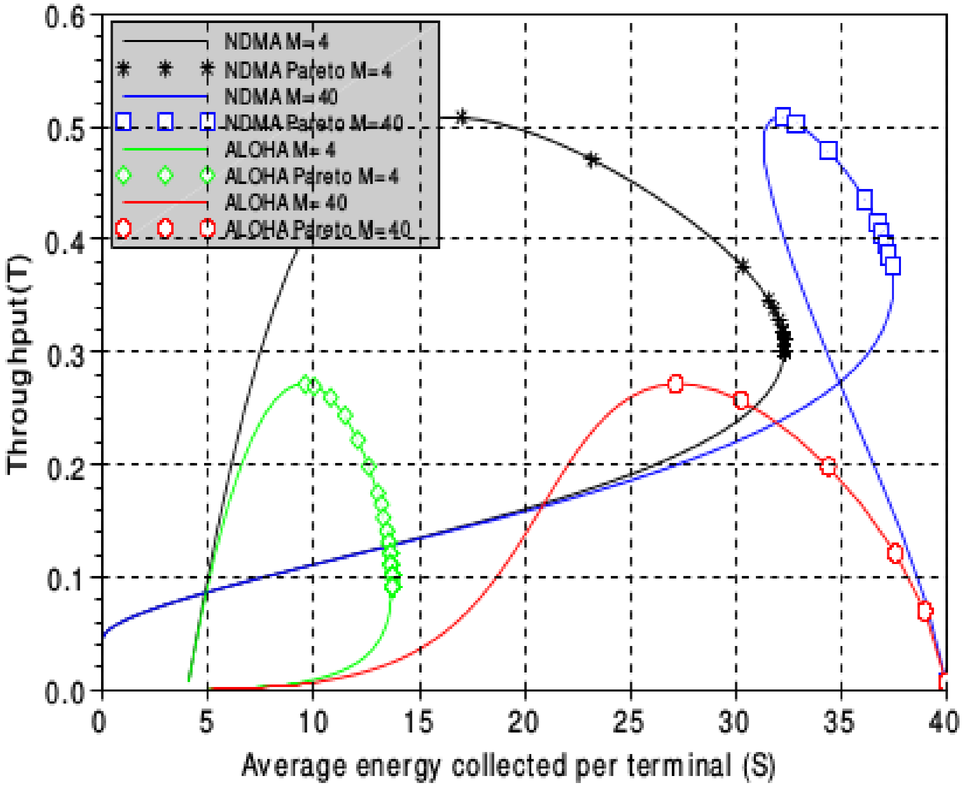
J=16 users M=4 M=40

noise



Superior performance in terms of throughput and energy

# Results



## Pareto tradeoff front

Shorter Pareto front for ALOHA when M=4

Shorter Pareto front for ND;MA when M=40

# Conclusions

- This paper presented an NDMA protocol where idle terminals are allowed to harvest the energy of the contending users for a finite number of slots.
- The protocol allows for a double use of collisions in random access : as a source of diversity for contention resolution, and as a source of energy to be potentially harvested/reused by idle terminals.
- NDMA not only provides with a higher throughput in comparison with conventional ALOHA, but also higher levels of energy that can be potentially collected by idle terminals due to the high levels of induced collisions created within the protocol operation.
- The trade-off between collected energy and achieved throughput was proved to be more flexible in NDMA when the number of time slots used for energy collection was large than its ALOHA counterpart.
- On the contrary, better Pareto optimal trade-off was found for ALOHA solutions when the number of time-slots used for energy harvesting was relatively lower.