# Cooperative Relay Scheme for Delay and Energy Constrained Multicast Network

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**Abstract:** We propose the reception decision scheme and the distributed relay decision scheme to reduce the processing power consumption in the baseband and the redundant retransmission in non-orthogonal cooperative multicast network. By simulation, it is shown that the $\epsilon$-outage constrained achievable multicast rate and energy efficiency achieved by proposed schemes are higher than ones by conventional schemes for low rate and short range communications in which processing power is comparable to transmission signal power.

Keywords: non-orthogonal cooperative relay scheme, wireless multicast network, outage constrained multicast rate, delay and energy constraint, processing power consumption

## 1. INTRODUCTION

Need for delay and energy constrained multicast network grows for disaster relief, military operation, and environmental monitoring. The non-orthogonal cooperative relay scheme for multicast network in Mergen *et al.* [2010] allows multiple nodes to simultaneously relay and the scaling of the achievable multicast rate is given as $\Theta(\text{loglog}n)$ as the number of cooperative nodes $n$ grows. However, it does not consider the power consumption for baseband processing and it may be comparable with the transmission energy as in Shu *et al.* [2009]. In such cases, the number of cooperative nodes can be severely restricted, so that the performance can be severely degraded. To remedy this problem, we propose multicast relay protocol having decision mechanisms for reception trials and relay trials to prevent power waste and improve the main metric shown later.

## 2. SYSTEM MODEL

A source is located at the center of a cluster and every node, which is uniformly distributed within the cluster, becomes a destination of the source. Every destination needs to receive data originated from the source and may act as a relay after it successfully receives the data. Non-orthogonal cooperative relay scheme allows multiple relays simultaneously transmit the same signal and signals from relays are merged at a receiver. The multicast signal is a narrowband one, so that the difference among propagation delays from multiple relays can be ignored. Denote $A$ as the number of allowable transmissions for a packet. The transmission rate of the packet is $r$(bits/sec/Hz) and it should be delivered to at least $\zeta$ portion of all destinations within $D$ time slots after being transmitted from a source. We consider a wireless sensor network in which a node transmits typically low-rate packet with a short-range relay distance. Accordingly, the processing power at a receiver and a transmitter of a node, $P_{cr}$ and $P_{ct}$, are not negligible compared with the transmission signal power, $P_t$ as We denote $N_i^{rx}[t]$ and $N_i^{tx}[t]$ as the number of receiving a packet and relaying it at the $i$-th node until the $t$ time slot after the source transmits it. Then, similarly as in Shin *et al.* [2001], the energy consumption at the $i$-th destination until the time slot $D$, $W_i[D]$, is given by

$$W_i[D] = (N_i^{rx}[D]P_{cr} + \mathbf{1}[N_i^{tx}[D] > 0]P_{ct} + N_i^{tx}[D]P_t)T_p, \tag{1}$$

where $\mathbf{1}[\cdot]$ is an indicator function and $T_p$ is the duration of a packet.

Multicast relay protocol in this paper is composed of reception decision, relay decision and the decision of $P_t$. A destination decides to decode the received signal based on reception decision probability $q_{rx}$. After a destination succeeds in decoding a packet, it decides to relay the packet based on relay probability $q_{relay}$ for the next retransmission and $P_t$ is determined according to $q_{relay}$.

We define the $\zeta$-outage event as that more than $(1-\zeta)$ of every destination do not succeed in decoding a packet until time slot $D$. Let $\mathcal{E}$ and $\mathcal{E}_s(D, P_B|r)$ respectively be the index set of all destinations in a cluster and the index set of destinations which successfully receive a packet

⋆ This work was supported by the National Research Foundation (NRF) of Korea grant (No. 2011-0029321) and the MSIP(Ministry of Science, ICT and Future Planning), Korea, under the C-ITRC(Convergence Information Technology Research Center) support program (NIPA-2013-H0401-13-2006) supervised by the NIPA(National IT Industry Promotion Agency).

with transmission rate $r$ using $P_B$ within $D$ time slots, $\mathcal{E}_s(D, P_B|r) \subset \mathcal{E}$. Accordingly, the $\zeta$-outage probability $P_\zeta^{out}(D, P_B|r)$ is given by

$$P_\zeta^{\text{out}}(D, P_B|r) = \Pr\left[\frac{|\mathcal{E} \setminus \mathcal{E}_s(D, P_B|r)|}{|\mathcal{E}|} > 1 - \zeta\right], \tag{2}$$

where $B \setminus A = \{x \in B | x \notin A\}$ and $\zeta$ is close to one.

The $\epsilon$-outage constrained achievable multicast rate by the relay scheme $\psi$, $\eta_\epsilon^\psi(D, P_B|\zeta)$, is defined as

$$\eta_{\epsilon,\zeta}^\psi(D, P_B|\zeta) = \max_{r \in \mathbf{r}_{\epsilon,\zeta}^\psi} \frac{r(1 - P_\zeta^{\text{out},\psi})(D, P_B|r))}{D}, \tag{3}$$

where $\mathbf{r}_{\epsilon,\zeta}^\psi = \{r | P_\zeta^{\text{out},\psi}(D, P_B|r) < \epsilon\}$.

## 3. PROPOSED SCHEME

### *3.1 Reception Decision Scheme*

Under the conventional scheme in Mergen *et al.* [2010], a destination tries to decode the received signal using only the threshold determined by the target false alarm probability. To prevent $P_{cr}$ from being wasted on the received signal of which signal power is not high enough to be successfully decoded, we propose that $q_{rx}$ is determined by the received signal power $\gamma[t]$, remaining time slots and the distribution on $r$. When the allowable minimum(maximum) transmission rate is $r_{\min}(r_{\max})$ and $r$ is assumed to uniformly distributed in $[r_{\min}, r_{\max}]$, the reception decision probability is defined as

$$q_{rx}\left(t, \gamma\left[t\right]|n\right) = \begin{cases} 0, & \gamma\left[t\right] \le 2^{r_{\min}} - 1 \\ \left(\dfrac{\gamma\left[t\right] - 2^{r_{\min}} + 1}{2^{r_{\max}} - 2^{r_{\min}}}\right)^{\frac{n(D-t)}{D-1}}, & 2^{r_{\min}} - 1 < \gamma\left[t\right] \le 2^{r_{\max}} - 1 \\ 1, & \gamma\left[t\right] > 2^{r_{\max}} \end{cases} \tag{4}$$

where $n \ge 0$ is the parameter which decreases the the reception decision probability.

### *3.2 Relay Decision Scheme*

Under the conventional scheme, every destination to succeed in decoding a packet relays it with the same $q_{\text{relay}}$. To reduce redundant retransmission from relays located close to transmitters, we propose relay decision scheme such that relays adjust $q_{\text{relay}}$ according to the expected distance from previous transmitters. When $d[m]$ is the expected width of the annulus shaped relay area of the $m$-th retransmission and information on path loss exponent $\alpha$ and $P_t$ is contained in the received packet, the proposed relay probability is defined as

$$q_{\text{relay}} = \exp\left(-\frac{\gamma[t]d[m]^\alpha\sigma^2}{CP_t[m-1]}\right) \tag{5}$$

$$d\left[m\right] = \frac{a\left(\sqrt{m} - \sqrt{m-1}\right)R}{\sqrt{A}}, \quad 0 \le a < 1, \tag{6}$$

where $a$ is the parameter which controls the $d[m]$. When the average of the total transmission signal power by all relays $P_{Tot}$ is given, transmission signal power at each relay $P_t$ is defined as

$$P_t\left[m\right] = \frac{P_{Tot}}{\pi R^2\lambda\left(m - \left\{\sqrt{m-1} + a\left(\sqrt{m} - \sqrt{m-1}\right)\right\}^2\right)}. \tag{7}$$

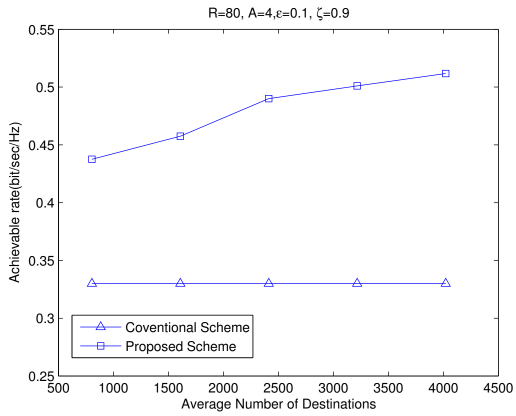


Fig. 1. $\epsilon$-outage achievable multicast rate

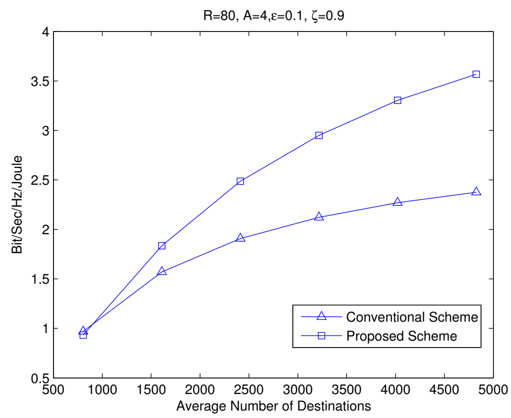


Fig. 2. Energy efficiency by proposed schemes

## 4. SIMULATION RESULTS

We use the parameters $P_{ct} = P_{cr} = 50$nW/bit used for $\mu$-AMPS(micro-Adaptive Multi-domain Power-aware Sensors) in Shin *et al.* [2001]. In Fig. 1, proposed schemes achieve higher $\epsilon$-outage achievable rate when the energy constraint for a packet $W[D]$ for a destination exists and $P_{Tot}$ is constant. Fig. 2 shows that proposed schemes also achieve higher energy efficiency with the increase of destinations' density.

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