TCast: A Transitional Region Aware Broadcast Protocol in Variable Wireless Link Qualities

Chunchao Liang[†], Sunho Lim[†], Manki Min[§], and Wei Wang[‡]

***Abstract*—As Internet-of-Things (IoT) and its applications are increasingly popular, where diverse multi-scale sensors and devices are seamlessly blended for ubiquitous communication infrastructure, broadcast operation still plays an essential role in scalable information dissemination to enhance information accessibility and availability. A unit-disk signal propagation model has been implicitly assumed and extensively applied to prior broadcast protocols, but we need to relax this assumption in reality. In this paper, we propose a transitional region aware broadcast protocol, called *TCast*, in variable wireless link qualities due to the signal propagation effects and non-uniform radiation pattern from the omni-directional antenna. The *TCast* is a stateless protocol and consists of two major operations, forwarder search and probabilistic rebroadcast. A sender neither maintains any neighbor information nor searches for a set of forwarders, but broadcasts a set of *Beacon* packets followed by a single *Data* packet. The sender repeatedly conducts the broadcast operations depending on the number of rebroadcasted packets overheard. Each receiver independently makes its own rebroadcast decision based on the number of received *Beacon* packets. A network-level random backoff mechanism is also proposed to avoid any packet contentions and collisions. The transitional region and its corresponding probability of packet reception are further investigated through a simple mathematical analysis. Extensive simulation experiments are also conducted using the OMNeT++, and simulation results indicate that the *TCast* shows competitive and scalable performance and is deployable in time-varying packet reception rates at receivers.**

***Index Terms*—Broadcast protocol, transitional region, wireless link quality.**

I. Introduction

Radio links often tend to be unreliable and unpredictable because of the signal propagation effects, such as path loss, shadowing, or multi-path propagation. The time- and space-varying link qualities can significantly affect the performance of communication protocol and algorithm embedded in the link or network layer. For example, in broadcast operation as a vital operation for scalable information dissemination in IoT, frequent single-hop link failures and their following retransmissions can significantly reduce the network throughput and increase the end-to-end latency and energy consumption. As pointed out in [1], low-power radio links are easily affected by ambient noises and interferences. The radio links of wireless sensor networks (WSNs) are more vulnerable than that of mesh or mobile ad hoc networks (MANETs).

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Most prior broadcast protocols [2], [3], [4], [5], [6], [7], [8], [9], [10] deploy an omni-directional antenna and simplify the link layer by adopting the unit-disk model of radio propagation. Each node is assumed to receive any incoming packet transmitted from the nodes located within its communication range. However, we need to relax this assumption because the intensity of radiation is not the same in all directions and the radiation pattern is not symmetric or omni-directional [11]. Although a sender uses the constant power for transmission, the actual transmission power measured in each receiver located within its communication range is not constant [12]. Thus, we also need to consider variable link qualities in designing communication protocol and algorithm to achieve the seamless communication and predictable performance.

In this paper, we propose a broadcast protocol in the presence of fluctuating wireless link qualities. Our contribution is summarized in two-fold:

- First, we propose a transitional region aware broadcast protocol, called *TCast*, in the presence of variable wireless link qualities. This is a stateless broadcast protocol, in which nodes do not maintain any neighbor information. A packet sender transmits a set of *Beacon* packets consecutively before sending a *Data* packet. Each receiver decides whether to rebroadcast the received *Data* packet based on the number of received *Beacon* packets. A network-level random backoff mechanism is also proposed to prevent nodes from simultaneous rebroadcasts. A simple analytical model is derived to further investigate the transitional region and its corresponding probability of packet reception.
- Second, we revisit three stateless broadcast protocols, *Flooding*, *Gossip1*, and *Gossip3*, modify them to work under variable wireless link qualities, and evaluate them with the TCast for performance comparison. Both Gossip1 and Gossip3, as a variant of original Gossip [4], are static and adaptive gossip protocols, respectively.

Extensive simulation experiments using the OMNeT++ [13] and their multi-dimensional analyses in terms of packet delivery ratio, rebroadcast fraction, number of senders, number of rebroadcasted data packets, and changes of number of broadcast trials have been conducted. Simulation results indicate that the TCast shows competitive and scalable performance compared to three other stateless broadcast protocols.

The rest of paper is organized as follows. Section II presents the proposed system model, broadcast protocol, and analytical model. Section III presents comprehensive simulation results

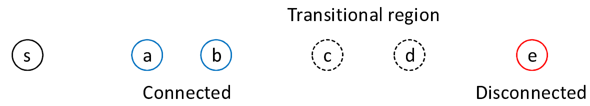


Fig. 1. Three packet reception regions from the sender (n_s) based on the log-normal shadowing model.

and their performance analyses. Finally, Section IV concludes the paper with future research direction.

II. The Proposed Broadcast Protocol

In this section, we first present a system model and then propose a transitional region aware broadcast protocol. A simple analytical model is also presented to deeply understand the transitional region and its corresponding probability of packet reception.

A. System Model

Due to the signal propagation effects, the received signal power decreases exponentially with the distance (d) between sender and receiver, e.g., $\frac{1}{d^2}$. The received power also depends on the intensity of radiation from antenna. In this paper, we first consider the log-normal shadowing model to calculate a realistic path loss, and the path loss between sender and receiver at the distance d, $PL(d)$, is expressed as,

$$PL(d) = PL(d_0) + 10\eta \log_{10}(\frac{d}{d_0}) + X_\sigma. \quad (1)$$

In Eq. 1, $PL(d_0)$ is the path loss at a reference distance d_0. η is the path loss exponent that shows the signal power decay rate. X_σ is a zero-mean Gaussian random variable with standard deviation σ. X_σ is a function of time and indicates the time-dependent transmission between sender and receiver. As shown in [14], the probability of packet reception from sender at the distance d can be expressed as,

$$p = (1 - \frac{1}{2} exp^{-\frac{\gamma(d)}{1.28}})^{8f}, \quad (2)$$

where f is the packet size. Also $\gamma(d)$ is signal-to-noise (SNR) ratio expressed as,

$$\gamma(d) = P_{tx} - PL(d) - P_n. \quad (3)$$

In Eq. 3, P_{tx} and P_n are the transmission output power and noise floor, respectively.

Second, we also consider three reception regions [14] based on the the log-normal shadowing model, as shown in Fig. 1. Note that the nodes (e.g., n_c and n_d) located in the transitional region show high-variance in packet reception rate (PRR).

B. Detail Operations

We propose a transitional region aware broadcast protocol, called *TCast*, and it consists of two major operations: forwarder search and probabilistic rebroadcast. The basic idea is that each node observes the number of received *Beacon* packets transmitted from sender and decides its rebroadcast decision. Since the wireless link quality is time-varying, it is not feasible to use the same forwarders or maintain the fixed number of forwarders for rebroadcast.

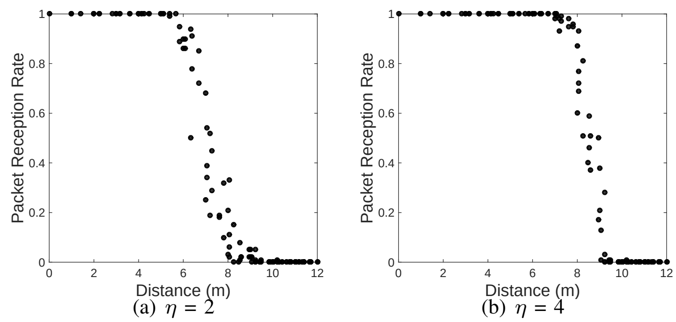


Fig. 2. The transitional regions characterized by η and their packet reception rates against the distance from sender.

First, we conduct a simple experiment and observe the transitional region by measuring the PRR based on the distance from a sender. In order to clearly identify the reception regions, nodes are arranged in a mesh topology, where the sender is located at left and top and repeatedly broadcasts a packet 100 times. As shown in Eq. 1, the transmission output power is set to 0 dBm and the signal decay rate (η) is changed for comparison. In Fig. 2, the PRR of each node is plotted and the η affects the width of transitional region. In Subfig. 2(b), since the link quality drops quickly, more nodes show higher PRR than that of nodes in Subfig. 2(a).

Second, in the TCast, the sender does not explicitly select forwarders but implicitly assists receivers in making a rebroadcast decision by sending a set of *Beacon* packets followed by a *Data* packet. The *Beacon* packets play an important role in identifying which reception region receivers are currently located in. For example, if a receiver receives all *Beacon* packets, it may imply that the receiver is in the connected region, located closely to the sender. If the receiver does not receive any packet, however, it may be located in the disconnected region. If the receiver receives only a subset of *Beacon* packets, it may consider that the receiver is located in the transitional region. Depending on the reception region identified, each receiver independently makes a rebroadcast decision. Note that the receiver located in the connected region does not rebroadcast the received *Data* packet in the TCast. The rationale behind this is that since the receiver is assumed to be located closely to the sender, its rebroadcast area can be significantly overlapped with the sender's and additional network coverage can also be minimized. The receiver in the disconnected region indeed cannot participate in any rebroadcast operation. The receiver located in the transitional region is preferred as a forwarder, because it is further located from the sender and can maximize the network coverage.

Third, we discuss the detail TCast operations using broadcast scenarios as shown in Fig. 3. In Subfig. 3(a), depending on the number of broadcast trials (k), a sender (n_s) broadcasts the number of *Beacon* packets (2^{k-1}) followed by a single *Data* packet, where k = 1, 2, and 3 (k_{max}). At each broadcast trial, if the sender does not overhear a pre-defined number (τ) of rebroadcasted *Beacon* or *Data* packets from the receivers before a timer expires, it increments k by one and broadcasts the 2^{k-1} number of *Beacon* packets followed by a *Data* packet

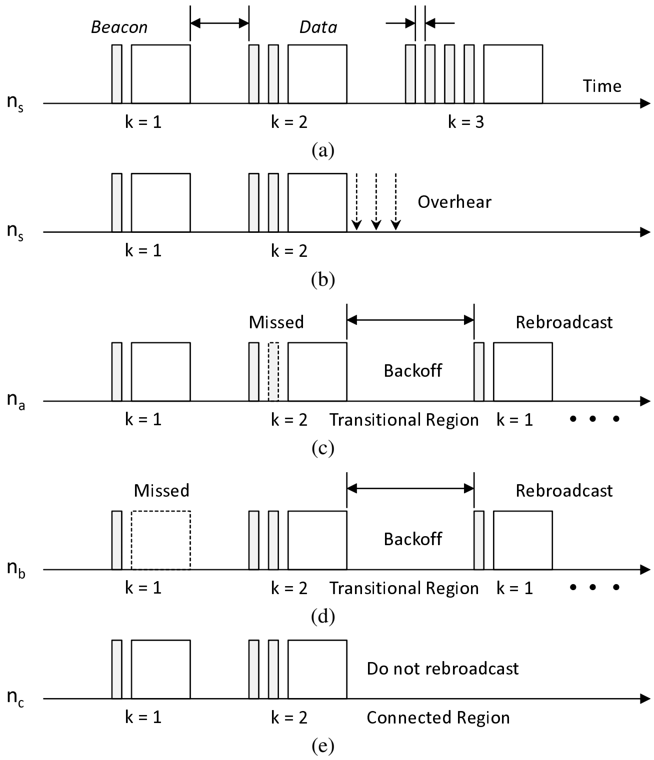


Fig. 3. Detail TCast operations and broadcast scenarios (e.g., a sender (n_s) and its neighbor nodes (n_a, n_b, and n_c)). Here, both *Beacon* and *Data* packets are marked as shaded and non-shaded rectangles, respectively. A dashed-arrow indicates the overhearing of rebroadcasted *Data* packet. Delay periods of between broadcast trials (Subfig. 3(a)), consecutive packets (Subfig. 3(a)), and random backoff for rebroadcast (Subfig. 3(c)) are shown.

Notations:

- k, k_{max}, τ, N_{beacon}, S_{Data}, bw: Defined before. Initially, k is 1.
- N_{ovhr}: A number of overheard *Beacon* or *Data* packets.
- f_{data}: A flag value of receiving the *Data* packet.
- $f_{k,fwd}$: A flag value of node being a forwarder at k^{th} broadcast trial.
- $pkt[p_{type}, nid, k]$: A packet is sent from a node with a node id (nid) at the k^{th} broadcast trial. Here, p_{type} is a packet type, either *Beacon* or *Data*.

$\diamond$ When a node (n_s) broadcasts a *Data* packet,
  k = 1;
  do {
    for 2^{k-1}
      Broadcast the $pkt[Beacon, s, k]$;
    Broadcast the $pkt[Data, s, k]$; N_{ovhr} = 0; k++;
    if Overhear any rebroadcast $pkt[p_{type}, i, k]$ /* where $i \neq s$ and $p_{type} \in$ {*Becon*, *Data*} */
      N_{ovhr}++;
  } **while** $N_{ovhr} < \tau \quad \wedge \quad k \leq k_{max}$;

$\diamond$ When a node (n_r) receives a packet,
  N_{beacon} = 0; f_{data} = False;
  switch (p_{type}) {
    case *Beacon*: N_{beacon}++; Break;
    case *Data*: f_{data} = True; Break;
  };
  if $N_{beacon} < 2^{k-1} \quad \wedge \quad f_{data}$ == False
    $f_{k,fwd}$ = True;
  if f_{data} == True $\wedge$ (($N_{beacon} < 2^{k-1}$) || ($N_{beacon} == 2^{k-1}$ $\wedge$ $f_{k-1,fwd}$ == True)) { /* where $k > 1$ for $f_{k-1,fwd}$ only */
    Execute the random backoff, ($N_{beacon} * \frac{2^{\tau}}{2^{k-1}} +$ Uniform$(0, \frac{2^{\tau}}{2^{k-1}} - 1)) * \frac{S_{Data}}{bw}$;
    Rebroadcast the $pkt[Beacon, r, k]$ followed by the $pkt[Data, r, k]$; /* where k = 1 */
  };

Fig. 4. The pseudo code of the TCast.

consecutively. In this paper, we set τ to 3 based on the prior study [6], [9], [10], where three or more strategically located nodes are often selected as a forwarder. The timer period is set to 2^{τ} times of *Data* transmission time for allowing the sender to overhear enough number of rebroadcast packets. As pointed out in [15], the overheard packet (i.e., *Beacon* or *Data*) can be used as an implicit acknowledgment. In Subfig. 3(b), for example, the sender does not overhear any rebroadcasted *Beacon* or *Data* packet at the first broadcast trial. Then the sender increments k by one (k = 2) and broadcasts two *Beacon* packets and a *Data* packet. After the second broadcast trial, the sender overhears the rebroadcasted *Beacon* or *Data* packets from the receivers and stops the broadcast operation. In Subfig. 3(c), if a receiver (n_a) receives a subset of *Beacon* packets with a *Data* packet, it considers itself as a forwarder. The receiver rebroadcasts both *Beacon* and *Data* packets piggybacked with k = 1 after a random backoff, if its received number of *Beacon* packets is less than 2^{k-1} at the sender's k^{th} broadcast trial. In Subfig. 3(d), if a receiver (n_b) receives a *Beacon* packet but does not receive a *Data* packet at the first broadcast trial, it is considered as a forwarder and waits for receiving the *Data* packet at the next broadcast trial. In case of when the receiver receives all *Beacon* and *Data* packets at the second broadcast trial, it is considered to be located in the transitional region rather than the connected region. This is because the receiver misses the *Data* packet at the first broadcast trial but receives it at the second broadcast trial. In this paper, the receiver considers the prior broadcast trial to make its rebroadcast decision when $k > 1$. Thus, the receiver rebroadcasts both *Beacon* and *Data* packets piggybacked with k = 1 after a random backoff even though the condition ($N_{beacon} < 2^{k-1}$) is not satisfied. In Subfig. 3(e), if a receiver (n_c) receives all *Beacon* and *Data* packets, it may be located in the connected region and does not rebroadcast the received *Data* packet.

Fourth, each node executes a network-level random backoff (see Subfig. 3(c)) to avoid any concurrent rebroadcast, resulting in possible packet contentions and collisions. The basic idea is that a node located further from the sender has a shorter random backoff period to increase the network coverage. In the TCast, nodes located in the transitional region are considered as a forwarder, which can be identified based on the number of received *Beacon* packets. Thus, when a node decides to rebroadcast the received *Data* packet, its random backoff period is, $(N_{beacon} * \frac{2^{\tau}}{2^{k-1}} + \text{Uniform}(0, \frac{2^{\tau}}{2^{k-1}} - 1)) * \frac{S_{Data}}{bw}$. Here, N_{beacon}, S_{Data}, and bw are the number of received *Beacon* packets, size of *Data* packet, and network bandwidth. Major operations of the TCast are also summarized in Fig. 4.

C. Analysis

We analyze the transitional region and its corresponding probability of packet reception. First, we approximate the boundary of the transitional region based on the PRR. In Fig. 5, we plot the PRR of nodes located around the sender against the distance, where the transmission output power and η are

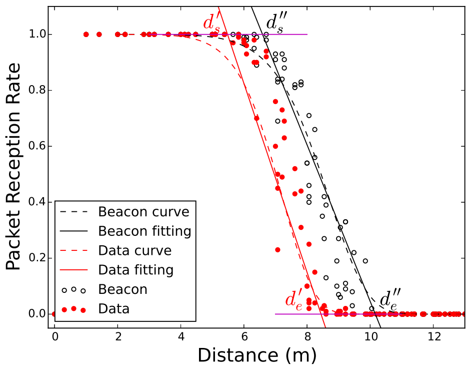


Fig. 5. A set of boundaries of two transitional regions indicated by start (d_s' and d_s'') and end (d_e' and d_e'') points in terms of the distance.

set to -15 dBm and 2.4, respectively. In order to identify the start (d_s) and end (d_e) points of the transitional region in terms of the distance, an oblique line that is best fit to the curve derived from Eq. 2 is deployed. Note that the transitional region is bounded to the distances corresponding to the PRR roughly between 0.9 and 0.1 in [14]. In this paper, however, we identify two transitional regions based on different packet sizes as the corresponding intersections of the oblique line and horizontal lines corresponding to the PRR = 1.0 and 0.0, respectively. Here, *Beacon* and *Data* packet sizes are set to 8 and 128 (Byte), respectively. As shown in Fig. 5, the transitional regions are indicated by d_s' (5.4828 (m)) and d_e' (8.445 (m)) for *Data* and d_s'' (6.5916 (m)) and d_e'' (10.1643 (m)) for *Beacon* packets. The transitional region with smaller packet is located further from the sender than that with bigger packet.

Second, the probability of *Data* packet reception for a node located in the transitional area is expressed as,

$$P_r' = \int_{d_s'}^{d_e'} \left(\frac{d_e' - x}{d_e' - d_s'}\right) \frac{2\pi x}{\pi(d_e'^2 - d_s'^2)} dx. \tag{4}$$

Here, $\frac{2\pi x}{\pi(d_e'^2 - d_s'^2)}dx$ is the probability that a node is located at x distance away from the sender. At this location, $(\frac{d_e' - x}{d_e' - d_s'})$ is the probability of the node to receive a packet. Eq. 4 can be simplified as,

$$P_r' = \frac{1}{3} + \frac{d_s'}{3(d_e' + d_s')}. \tag{5}$$

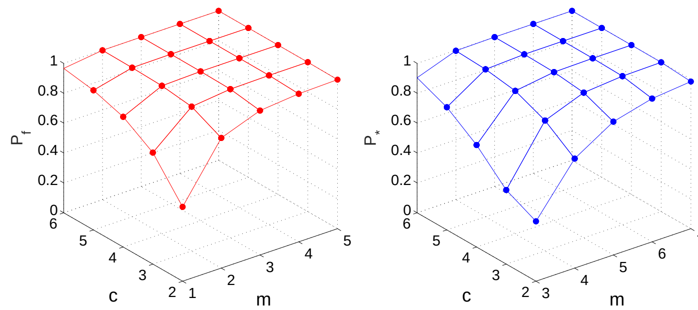
Similarly, the probability of *Beacon* packet reception[1] is expressed as P_r'' with d_s'' and d_e''. For the sake of simplicity, we average P_r' and P_r'', denoted as $\bar{P}_r$, and use d_s and d_e for the rest of analysis. Since $d_e > d_s > 0$,

$$\frac{1}{3} < \bar{P}_r < \frac{1}{2}. \tag{6}$$

Eq. 6 is the case when the sender broadcasts a packet once. If the sender broadcasts twice, Eq. 6 becomes,

$$\frac{4}{9} < 2\bar{P}_r(1 - \bar{P}_r) < \frac{1}{2}. \tag{7}$$

[1]We use $P_r'' = \int_{d_s''}^{d_e''} (\frac{d_e'' - x}{d_e'' - d_s''}) \frac{2\pi x}{\pi(d_e''^2 - d_s''^2)} dx$ and simplify it as $P_r'' = \frac{1}{3} + \frac{d_s''}{3(d_e'' + d_s'')}$.



(a) P_f (b) P_*

Fig. 6. P_f and P_* against different number of nodes located in the transitional region and number of broadcasts repeated from the sender.

Suppose there are m nodes in the transitional region and the sender broadcasts a packet c times ($c > 1$). The probability of all m nodes to receive all c packets is,

$$P_{m,c} = [(\bar{P}_r)^c]^m. \tag{8}$$

On the other hand, the probability of all m nodes to miss all c packets is,

$$P_{m,0} = [(1 - \bar{P}_r)^c]^m. \tag{9}$$

If a node does receive one or more but not all c packets, it is assumed to be located in the transitional region and becomes a forwarder. Thus, the probability of node to become a forwarder is,

$$P_f = 1 - P_{m,c} - P_{m,0}. \tag{10}$$

In [6], [9], [10], three or more strategically located nodes are often selected as a forwarder under the unit-disk signal propagation model. In this paper, we also investigate if three or more nodes are located in the transitional region and are considered as a forwarder. The probability of one of m nodes to receive one or more but not all packets from the sender, while the rest of m - 1 nodes receives all packets or does not receive any packet, is,

$$P_1 = \binom{m}{1}[1-(\bar{P}_r)^c-(1-\bar{P}_r)^c]\{[(1-\bar{P}_r)^c]^{m-1}+[(\bar{P}_r)^c]^{m-1}\}. \tag{11}$$

The probability of two of m nodes to receive one or more but not all packets from the sender, while the rest of m - 2 nodes receives all packets or does not receive any packet, is,

$$P_2 = \binom{m}{2}[1-(\bar{P}_r)^c-(1-\bar{P}_r)^c]^2\{[(1-\bar{P}_r)^c]^{m-2}+[(\bar{P}_r)^c]^{m-2}\}. \tag{12}$$

Thus, the probability of three or more nodes to be selected as forwarders is,

$$P_* = P_f - P_1 - P_2. \tag{13}$$

We visualize both P_f and P_* by changing m and c in Fig. 6. P_f increases as the sender repeatedly sends a packet to more number of nodes located in the transitional region as shown in Subfig. 6(a). P_* shows lower probabilities than that of P_f because three or more nodes are selected as forwarders and are located in the transitional region as shown in Subfig. 6(b).

Since the proposed analysis is intended only to estimate the performance trend, we conduct detail performance evaluation through extensive simulation experiments in the following section.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Transmission output power (P_{tx})	-15 dBm
Reference distance (d_0)	1.0 m
Path loss at reference distance ($PL(d_0)$)	56 dBm
Path loss exponent (η)	2.4
Noise floor (P_n)	-100 dBm
Standard deviation (σ)	0.5
$Data$ packet size	128 Byte
$Beacon$ packet size	8 Byte
Overheard packet threshold (τ) [10]	3

III. PERFORMANCE EVALUATION

A. Simulation Testbed

We develop a customized discrete-event driven simulator by using the OMNeT++ [13] with extended library functions for WSNs, Castalia [16], which uses the log-normal shadowing model to calculate path loss. A 100×100 (m^2) rectangular network is deployed, where 400 to 2,000 nodes are randomly distributed. The radio model is based on the CC2420 with a nominal data rate of 250 (Kbps). A single source node repeatedly broadcasts a packet. The proposed TCast is compared with three stateless broadcast protocols: *Flooding*, *Gossip1(0.65, 1)*, and *Gossip3(0.65, 1, 1)*. In the Flooding, each node rebroadcasts a newly received packet exactly once. The Gossip1 is a static gossip protocol, where a source node and its direct neighbor nodes broadcast a packet with a probability 1.0, but other nodes rebroadcast with a probability 0.65. The Gossip3 is similar to the Gossip1 but it is an adaptive gossip protocol. If a packet receiver decides not to broadcast the packet with a probability 0.35 but cannot overhear at least one rebroadcasted packet, it rebroadcasts the packet. The performance of TCast is measured by changing k from 1 to 3 (k_{max}), denoted as *TCast(k)*. We embed a random backoff mechanism into the Flooding, Gossip1, and Gossip3 to prevent nodes from simultaneous rebroadcasts. The simulation results are the average of 100 simulation runs. The major simulation parameters are summarized in Table I.

B. Simulation Results

In this paper, we measure the performance in terms of (i) packet delivery ratio (PDR), (ii) rebroadcast fraction, (iii) number of senders, and (iv) number of rebroadcasted data packets. We also observe the changes of k against different node densities in the network.

First, we compare the performance in terms of the PDR and rebroadcast fraction in Fig. 7. The TCast(3) shows a competitive PDR performance to the Flooding and Gossip3, except when the number of deployed nodes is low (e.g., 400) in Subfig. 7(a). The Gossip1 shows the lowest PDR because each node broadcasts a packet with a static broadcast probability, regardless of possible broadcast failures from the nodes located in the transitional region. When the number of deployed number of nodes is 600, the TCast(3) achieves almost 90% PDR. In Subfig. 7(b), the TCast shows the lowest rebroadcast fraction as the number of deployed nodes increases. As the network density increases, more nodes located

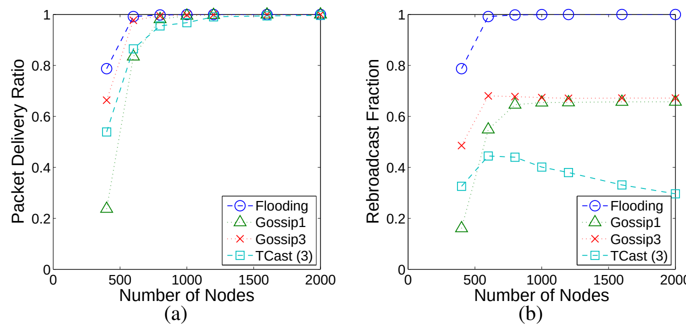


Fig. 7. Comparisons of packet delivery ratio and rebroadcast fraction.

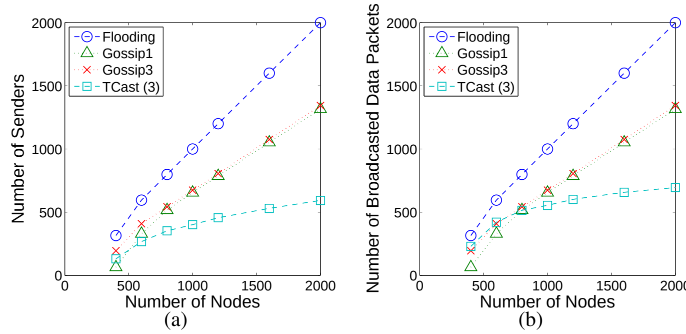


Fig. 8. Comparisons of number of senders and broadcasted data packets.

in the transitional region can rebroadcast the received packets. The Flooding shows 100% rebroadcast fraction due to its blind rebroadcasts. Compared to the Flooding, the Gossip1 and Gossip3 can reduce the rebroadcast fraction but they still show as high as 65%.

Second, Fig. 8 shows both number of senders and number of rebroadcast data packets. The TCast(3) shows the lowest number of senders in Subfig. 8(a). This implies that the TCast can achieve the competitive PDR (see Subfig. 7(a)) with less number of packet senders. In the Flooding, Gossip1, and Gossip3, however, they show a linearly increasing number of senders as the number of deployed nodes increases. Similarly, the TCast(3) achieves the lowest number of rebroadcast data packets compared to the rest of protocols in Subfig. 7(b). This is because the TCast(3) restricts the rebroadcasts only to the nodes located in the transitional region, and thus both number of senders and rebroadcasted data packets are minimized. However, other three protocols consider any node as a forwarder and show the same results. Although the TCast(3) may rebroadcast data packets three times, both number of senders and rebroadcasted data packets are even smaller than that of other three protocols.

Third, we further evaluate the performance of TCast(k) by changing k from 1 to 3 in terms of the PDR and rebroadcast fraction in Fig. 9. As k increases, the PDR increases because more number of data packets can be broadcasted if senders cannot overhear τ number of rebroadcasted packets in 9(a). Here, the TCast(1) shows the lowest PDR because senders do not rebroadcast again even under potential packet losses, similar to the Gossip1. As k increases, the rebroadcast fraction increases in Subfig. 9(b). This is because higher k implies

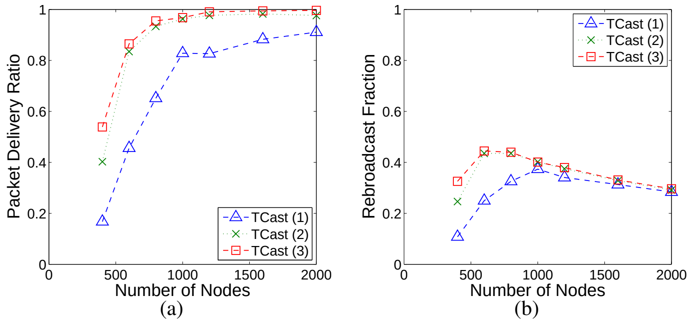


Fig. 9. Comparisons of packet delivery ratio and rebroadcast fraction.

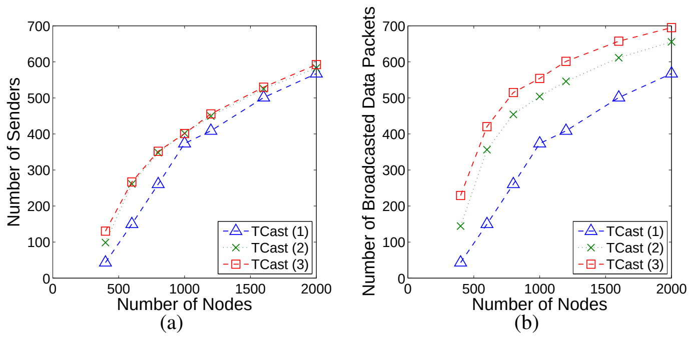


Fig. 10. Comparisons of number of senders and broadcasted data packets.

more data rebroadcasts from senders located in the transitional region.

Fourth, Fig. 10 shows the performance of TCast(k) in terms of number of senders and number of rebroadcast data packets. The TCast(1) shows the lowest number of senders, but both TCast(2) and TCast(3) show the similar number of senders in Subfig. 10(a). As the number of deployed nodes increases, unlike the Flooding, Gossip1, and Gossip3, the number of senders does not linearly increase. Note that the number of senders does not differ much among the TCast(k) but the performance gap becomes larger in Subfig. 10(b), where k is 1, 2, and 3.

Lastly, we observe the changes of k against different node densities in the TCast(3). In Fig. 11, we count the number of senders corresponding to the number of broadcast trials. Here, the number of senders is much smaller than the number of nodes in the network because only a small set of nodes (i.e., forwarders) rebroadcasts the received *Data* packet. At the first broadcast trial (k = 1), the number of senders in high node density (i.e., 1,200) is higher than that in low node density (i.e., 600) because more nodes located in the transitional region are found and become a forwarder. At the third broadcast trial (k = 3), however, the number of senders in low node density is higher than that in high node density. Since very few nodes are found the transitional region, the sender does not overhear enough number of packets and repeatedly rebroadcasts packets with the incremented k.

IV. Concluding Remarks

In this paper, we proposed a transitional region aware broadcast protocol in the presence of variable packet reception

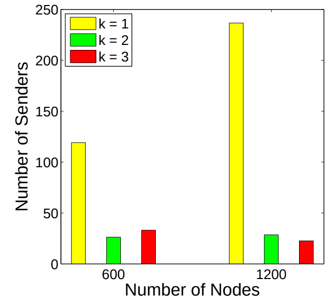


Fig. 11. Number of senders corresponding to the number of broadcast trials in the Tcast(3).

rates at receivers. This is a stateless broadcast protocol and its simple mathematical analysis are also suggested. Compared to the Flooding, Gossip1, and Gossip3 protocols, the proposed protocol shows competitive and scalable performance in terms of PDR, rebroadcast fraction, number of senders, and number of rebroadcasted data packets. Extensive performance analyses indicate that the proposed protocol can be deployable in variable wireless link qualities.

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