Possible Energy Consumption of Messages in an Opportunistic Network

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Abstract. In disaster-tolerant (DTN) and vehicle-to-vehicle (V2V) networks, each node communicates with other nodes in infrastructure-less networks using wireless networks. Here, a node has to wait for opportunity that the node can communicate with another node. Even if a message is successfully forwarded to a neighboring node, the node might be unable to forward the message to any node. Hence, each node has to retransmit a message in more times. In our previous studies, the possible energy consumption (PEC) of a message stored in a node is proposed, which shows how much energy the node is expected to consume to retransmit the message. The PEC of a message is defined to depend on the delivery ratio to the destination node. In this paper, we newly propose an algorithm to retransmit messages where the interval of retransmissions of each message is decided based on the PEC. In the evaluation, we evaluate the retransmission algorithm in terns of number of retransmissions and delivery time.

Keywords: Energy-efficient opportunistic networks · Possible energy consumption (PEC) · Optimistic node · Pessimistic node

1 Introduction

The opportunistic networks [4,7] which use wireless communication are getting more important in various applications like V2V (vehicle-to-vehicle) networks [3] and DTN (Delay/disaster Tolerant Networks) [5]. Here, each node has to wait for some node which comes in the communication range to deliver messages to the destination nodes. On receipt and transmission of a message, a node keeps the message in the buffer. Once a node p_i finds some node p_j in the communication range, the node p_i retransmits a message m in the buffer to the node p_j.

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In many opportunistic routing protocols like Epidemic [10], Prophet [1], Spray and wait [8], MAC [9], and DOMAC [2], the number of messages transmitted in networks and kept in the memory buffer and the delivery ratio of messages are tired to be decreased and increased, respectively. A node consumes electric energy to transmit and receive messages. The longer a message is kept in the buffer of a node, the more amount of energy the node consumes by retransmitting the message. The concept of possible energy consumption (PEC) of each message kept in the buffer is proposed in our previous paper, [6]. The PEC of a message in a node shows how much energy the node is expected to consume to retransmit the message. The PET of a message depends on the ratio of the message to the destination node. The smaller delivery ratio, the larger PEC. The effective energy residue (ER) of each node is, the difference of the maximum energy residue to the total PEC of messages in the buffer. The smaller the ER of a node is, the more number of times the node can retransmit each message in the buffer.

A node whose ER is larger and smaller is *optimistic* and *pessimistic*, respectively. In this paper, we propose a retransmission algorithm to retransmit messages by changing the inter-retransmission interval. The inter-retransmission interval is decided on the types of source and destination nodes. In this paper, we propose four types of the retransmission algorithms. In the evaluation, we show the expected number of retransmissions and expected delivery time of each message in the retransmission algorithm.

In Sect. 1, we present a system model and PEC of a message. In Sect. 2, we propose the retransmission algorithm. In Sect. 3, we evaluate the retransmission algorithm.

2 System Model

2.1 Wireless Networks

A system S is composed of mobile nodes $p_1, ..., p_n$ $(n \geq 1)$ which are interconnected in wireless networks. Each node p_i communicates with other nodes in wireless networks. A node p_i can communicate with another node p_j $(p_i \leftrightarrow p_j)$ only if the node p_j is in the communication range of the node p_i.

A node p_i supports the buffer BF_i to store messages which the node p_i receives and sends. Let sb_i be the size of the buffer BF_i, i.e. the maximum number of messages which the node p_i can store in the buffer BF_i. Let mm_i be the number of message in the buffer BF_i. On receipt of a message m, a node p_i stores the message m in the buffer BF_i if $mm_i < sb_i$. Otherwise, node p_i cannot receive message m. For each message m, a TTL (time-to-line) variable $m.c$ is manipulated. On receipt of a message m, the variable $m.c$ is 0 and the message m is stored in the buffer BF_i. A message m in the buffer BF_i is eventually retransmitted to another node, e.g. each time some node comes in the communication range. Each time a node p_i retransmits a message m, the variable $m.c$

is incremented by one in the node p_i. If the variable $m.c$ gets larger than the maximum number xr_i of retransmisions, the message m is removed in the buffer BF_i.

2.2 Energy Consumption

A node p_i consumes electric energy to transmit and receive a message. Let SE_i and RE_i be the electric energy to be consumed by a node p_i to transmit and receive a message, respectively. A message m in the buffer BF_i of a node p_i is retransmitted if some node p_j is in the communication range of p_i. We consider how much energy a node p_i is expected to consume to retransmit a message m until the message m is delivered to the destination node. The energy to be consumed by anode p_i depends on the loss probability of each message m to the destination node p_j. Let $m.dst$ stand for the destination node of a message m. Let f_{ij} be the probability that a node p_i cannot deliver a message to a destination node p_j. Let xr_i be the maximum number of retransmission of each message in a node f_i. If a node p_i can retransmit a node p_j a message infinite times, the expected number of transmissions is $1/(1 - f_{ij})$. The probability that a message is delivered to the destination node p_j by k transmissions is $1 - f_{ij}^k$. Let c_{ij} and d_{ij} be k/xr_{ij} (< 1) where k is number where $1 - f_{ij}^k \leq 0.8$ and $1 - f_{ij}^k \geq 0$. respectively.

In this paper, the expected power $PR_{ij}(k)$ [W] to be consumed by a node p_i to retransmit a message m where $m.dst = p_j$ and $m.c = k$ ($\leq xr_i$), i.e. which is already retransmitted k times, is defined as follows (Fig. 1):

$$PR_{ij}(k) = \begin{cases} 1 \;\; for \;\; k \leq d_{ij} \cdot xr_i. \\ (1 - \frac{(k - d_{ij} \cdot mr_i)^2}{(c_{ij} - d_{ij})^2 \cdot mr_i^2})^2 \;\; for \;\; d_{ij} \cdot xr_i \; < \; k \;\; \leq c_{ij} \cdot xr_i. \\ 0 \;\; for \;\; c_{ij} \cdot mr_{ij} \; < \; k. \end{cases} \quad (1)$$

$PR_{ij}(d_{ij} \cdot xr_i) = 1$ and $PR_{ij}(c_{ij} \cdot xr_i) = 0$.

For a message m where $m.dst = p_j$ and $m.c$ is k, the *possible energy consumption* (PEC) $NPE_{ij}(k)$ is defined as follows:

$$NPE_{ij}(k) = SE_{ij} \cdot PR_{ij}(k). \quad (2)$$

Figure 1 shows $NPE_{ij}(k)$ for $0 \leq k \leq xr_i$. For $k \leq d_{ij} \cdot xr_i$, $NPE_{ij}(k) = SE_i$. For $c_{ij} \cdot xr_i \geq k > d_{ij} \cdot xr_i$, $NPE_{ij}(k)$ exponentially decreases since there is higher possibility that the message m is delivered to the destination node: For $k > c_{ij} \cdot xr_i$, $NPE_{ij}(k) = 0$.

The *possible energy consumption* (PEC) $PE_{ij}(m)$ of a node p_i for each message m whose destination is p_i in the buffer BF_i of the node p_i is as follows:

$$PE_{ij}(m) = \begin{cases} SE_{ij} \;\; for \;\; k \leq d_{ij} \cdot xr_i. \\ SE_{ij} \cdot (1 - \frac{(k - d_{ij} \cdot xr_i)^2}{(c_i - d_{ij})^2 \cdot xr_i^2})^2 \;\; for \;\; d_{ij} \cdot xr_i \; < \; k \;\; \leq c_{ij} \cdot xr_i. \\ 0 \;\; for \;\; c_{ij} \cdot xr_i \; < \; k. \end{cases} \quad (3)$$

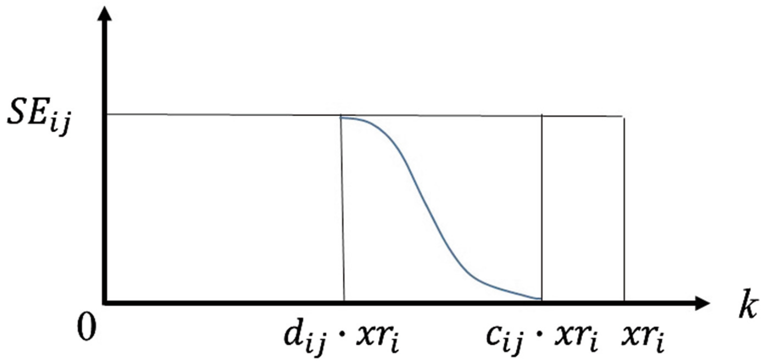

Fig. 1. Power consumption of a node p_i to retansmit a message to p_j.

$PE_{ij}(m) = SE_i$ if a message m is retransmited a fewer times than $d_{ij} \cdot xr_i$. The PEC $PE_{ij}(m)$ decreases in the square of the number $m.c$ of retransmissions of a message m. Each message m is retranmitted at most $c_{ij} \cdot xr_i$ times.

Let xPE_{ij} stand for the maximum PEC of each message m where $m.dst = p_j$, i.e. $xPE_{ij} = PE_{ij}(m)$ where $m.c = 0$ for each message m.

A node p_i consumes the energy SE_i to retransmit a message m. Since a message m in the buffer BF_i is already retransmitted $m.c$ times, the node p_i already consumes the transmission energy $TE_i(m)$ to retransmit the message m as follows:

$$TE_i(m) = SE_i \cdot m.c. \tag{4}$$

Let xE_i be the maximum energy residue which the battery of a node p_i can support. A variable R_i ($\leq maxC_i$) denotes the energy residue of a node p_i. Initially R_i is xE_i, i.e. the buttery is fully charged. Each time a node p_i receives and transmits a message, the energy residue R_i is decremented by the energy consumption RE_i and SE_i, respectively. TPE_i is the total PEC of a node p_i to transmit every message in the buffer BF_i. The total PEC TPE_i of a node p_i is defined to be summation of PEC of all the messages in the buffer BF_i as follows:

$$TPE_i = \sum_{m \in BF_i} PE_{i,m.dst}(m). \tag{5}$$

The $effetive\ energy\ residue$ (ER) ER_i of a node p_i is as follows:

$$ER_i = R_i - TPE_i. \tag{6}$$

Initially, $R_i = ER_i = R_i$ and $TPE_i = 0$ for each node p_i. The ER_i means electric energy which a node p_i can consume to newly transmit and receive message.

The effective energy residue ER_i and energy residue R_i are manipulated each time a node p_i transmits and receives a message m in the Algorithm 1.

Algorithm 1: [p_i transmits a message m]

input : m = message to be transmitted, where m.dst = p_j;
if $m.c > c_{ij} \cdot xr_i$ **then**
    $TPE_i = TPE_i - NPE_{ij}(m.c) + NPE_{ij}(m.c+1)$;
    $R_i = R_i - SE_i$;
    $ER_i = R_i - TPE_i$;
    $m.c = m.c + 1$;
    transmit m;
else
    remove m;

A node p_i receives a message m whose destination is p_i, i.e. $m.dst = p_j$ in the Algorithm 2.

Algorithm 2: [p_i receive a message m]

m = **receive**();
if BF_i *is not full* **then**
    $m.c = c_{ij} \cdot xr_i$;
    $TPE_i = TPE_i - PE_{ij}(m)$;
    $R_i = R_i - RE_i$;
    $ER_i = R_i - TPE_i$;
    store m **in** BF_i;
else
    /* buffer full */
    select a message m in BF_i, where $PE_{ij}(m)$ is the smallest;
    remove m;

If $R_i \leq 0$, a node p_i can neither transmit nor receive any message. On the other hand, even if $ER_i \leq 0$, a node p_i can send and receive messages but may not be able to retransmit every message in the buffer BF_i. It is noted $R_i \geq ER_i$.

The more amount of the effective energy residue ER_i of a node p_i, the more optimistic the node p_i is, i.e. the node p_i can more often retransmit messages. A node p_i is *optimistic* if the effective energy residue ER_i is larger. For example, once an optimistic node p_i finds another node p_j to be in communication range, the node p_i transmits messages to the node p_j. On the other hand, if the ER_i of a node p_i is smaller, the node p_i is *pessimistic*, i.e. the node p_i does not often retransmit messages. For example, even if another node p_j is in the communication range, a pessimistic node p_i may not send messages to the node p_j. A pessimistic node p_i only sends messages to a node p_j which is more optimistic, i.e. whose effective energy residue ER_i is larger.

3 Retransmission Algorithm

Suppose a node p_j is in the communication range of a node $p_i(p_i \leftrightarrow p_j)$. The node p_i retransmits a message m in the buffer BF_j, whose destination node of the message m is a node p_j, i.e. $m.dst = p_j$. The node p_i changes the inter-retransmission interval of a message m depending on the type of the destination node p_j and its own type. The fewer number of retransmissions, the smaller energy the node p_i consumes. Let xr_i be the maximum number of retransmissions of each message at a node p_i. Let $rt_{ij}(k)$ show time a node p_i retransmits a message m where $m.dst = p_j$ at the kth retransmission ($k \leq xr_i$). $rt_{ij}(k+1) \geq rt_{ij}(k)$ for $k \leq 1$. That is, a node p_i retransmits a message m to a node $p_j rt_{ij}(k) - rt_{ij}(k-1)$ time units after $(k-1)$th retransmission. The difference $rt_{ij}(k) - rt_{ij}(k-1)$ gives the inter-retransmission time between the $(k-1)$th and kth retransmissions.

An optimistic node p_i thinks a message m can be delivered to the destination node once the node p_i transmits the message m. Hence, the inter-transmission time is longer. On the other hand, a pessimistic node p_i thinks a message m cannot be delivered to the destination node. Hence, a pessimistic node p_i often retransmits the message m. That is, the inter-retransmission time is shorter.

The retransmission time $rt_{ij}(k)$ of the kth retransmission of a node p_i is decided depending on the types of a node p_i and a destination node p_j as follows:

1. [**Optimistic-Optimistic (OO)**]. If an optimistic node p_i transmits a message m to an optimistic node p_j, $rt_{ij}(k) = (xr_{ij}/2) \cdot k$. The inter-retransmission time $rt_{ij}(k) - rt_{ij}(k-1)$ is constant $xr_{ij}/2$.
2. [**Pessimistic-Pessimistic (PP)**]. If a pessimistic node p_i transmits a message m to a pessimistic node p_j, $rt_{ij}(k) = 2k$. Here, the inter-retransmission time $rt_{ij}(k) - rt_{ij}(k-1)$ is constant 2. Every two time units, the node p_i retransmits the message m.
3. [**Optimistic-Pessimistic (OP)**]. If an optimistic node p_i retransmits a message m to a pessimistic node p_j, the larger number k of retransmissions, the longer inter-retransmission interval. In this paper, $rt_{ij}(k) = k(k+1)/2$, for $k \leq xr_i$. $rt_{ij}(k) - rt_{ij}(k-1)$ $(= k) > rt_{ij}(k-1) - rt_{ij}(k-2) (= k-1)$.
4. [**Pessimistic-Optimistic (PO)**]. If a pessimistic node p_i retransmits a message m to an optimistic node p_j, the inter-retransmission interval decreases as k gets larger. In this paper, $rt_{ij}(k) = k(2xr_{ij} - k + 1)/2 - 1$ for $k \leq xr_i$. $rt_{ij}(k) - rt_{ij}(k-1)$ $(= xr_{ij} - k + 1) < rt_{ij}(k-1) - rt_{ij}(k-2)$ $(= xr_{ij} - k + 2)$.

Figure 2 shows the inter-retransmission interval $rt_{ij}(k)$ for the OO, SO, SP, and PP types.

Table 1 summarizes the actions of a source node p_i to a destination node p_j.

Table 1. Optimistic and pessimistic actions.

p_i \ p_j	Optimistic	Pessimistic
Optimistic	OO	SO
Pessimistic	SP	PP

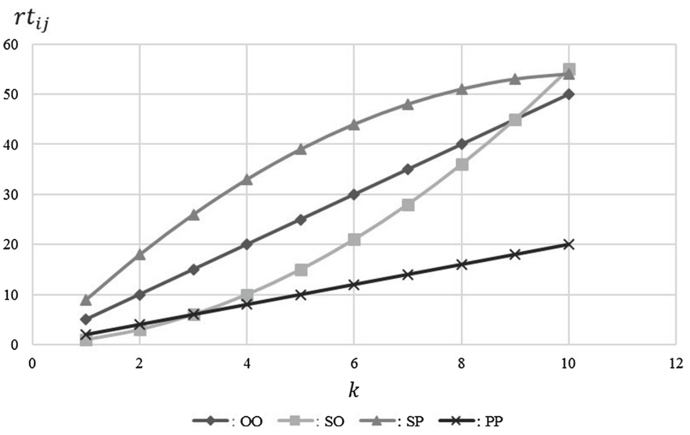

Fig. 2. Inter-retransmission interval ($xr_{ij} = 10$).

4 Evaluation

We consider a pair of a source node p_i and a destination node p_j. Let $f(x)$ be the loss probability (LP) that the node p_j does not receive a message which the node p_i retransmits the message x time units later. In fact, the variable x shows the distance between the nodes p_i and p_j. Let xr be the maximum number of retransmissions of a message of the node p_i. The loss probability $f(x)$ changes as x changes. Let xrt be the maximum number of $rt(xr)$ for OO, SO, SP, and PP types. In the evaluation, $xr = 10$ and $xrt = 55$. We consider two types of loss probability (LP) function, $f(x) = x/xrt$ and $f(x) = 1 - x/xrt$. The first loss probability (LP) function $f(x) = x/xrt$ means the node p_j is leaving the node p_i. The loss probability function $f(x)$ monotonically increases. The second loss probability function $f(x) = 1 - x/xrt$ shows the node p_j is approaching to the node p_i, i.e. $f(x)$ monotonically decreases.

A function $rt(k)$ gives time the node p_i does the kth retransmission of a message as discussed in the preceding section.

Here, the expected number RN of retransmissions to deliver a message to the node p_j is given as follows.

$$RN = (1 - f(rt(1))) + 2 \cdot (1 - f(rt(2))) \cdot f(rt(1)) \\ + ... + xr \cdot (1 - f(rt(xr))) \cdot f(rt(1)) \cdot ... \cdot f(rt(xr - 1)). \quad (7)$$

The expected time RT to delivery a message to the destination node p_j is as follow.

$$RT = (1 - f(rt(1))) \cdot rt(1) + (1 - f(rt(2))) \cdot f(rt(1)) \cdot rt(2) \\ + ... + (1 - f(rt(xrn))) \cdot f(rt(1)) \cdot ... \cdot f(rt(xrn - 1)) \cdot rt(xrn). \quad (8)$$

Figures 3 and 4 show the expected number RN of retransmissions of the OO, SO, SP, and PP types for the number k of retransmissions for the first and second loss probability functions. For the first loss probability function f where the node p_j is leaving the node p_i, the SO types implies the fewest number RN of retransmissions. For the second probability function of where the node p_j is approaching to the node p_i, RN is the smallest for $k \leq 6$ in the PP type and $k > 6$ in the SP type.

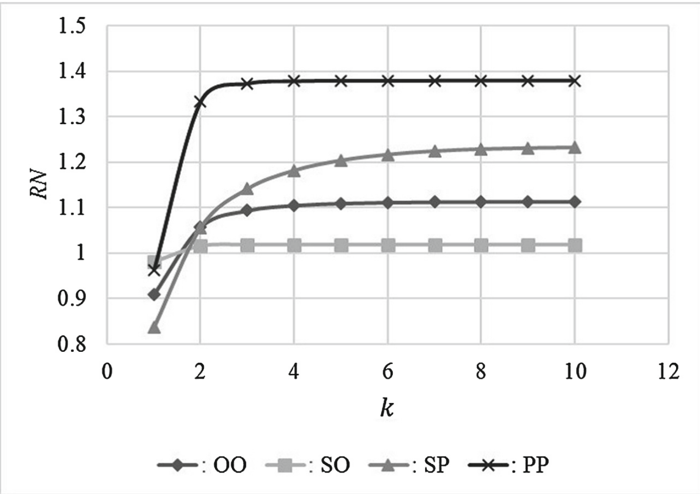

Fig. 3. Expected number RN of retransmissions ($xr = 10$, LP type 1).

Figures 5 and 6 show the expected delivery time RT to the OO, SO, SP and PP types with number k of retransmissions for the first and second loss probability functions. For the first and second loss probability functions f, the delivery time RT is the shortest in the SO type and in the PP type, respectively.

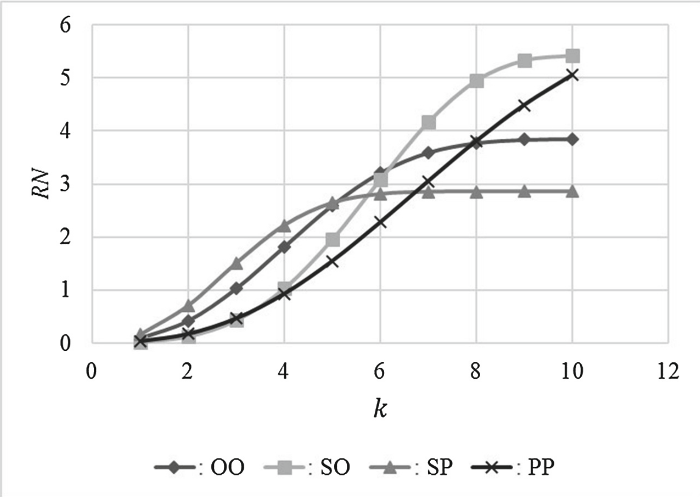

Fig. 4. Expected number RN of retransmissions ($xr = 10$, LP type 2).

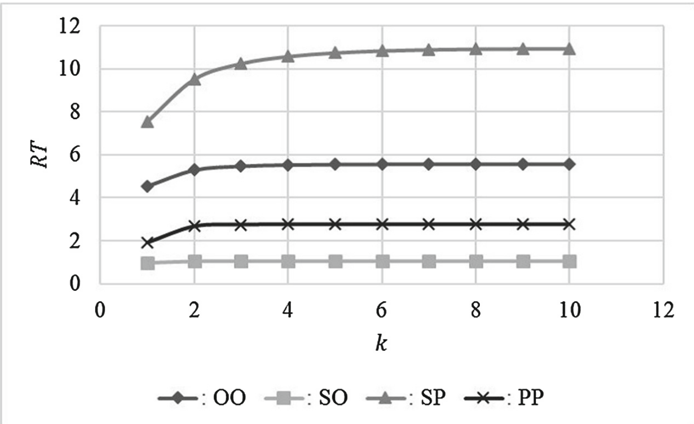

Fig. 5. Expected delivery time RT ($xr = 10$, LP type 1).

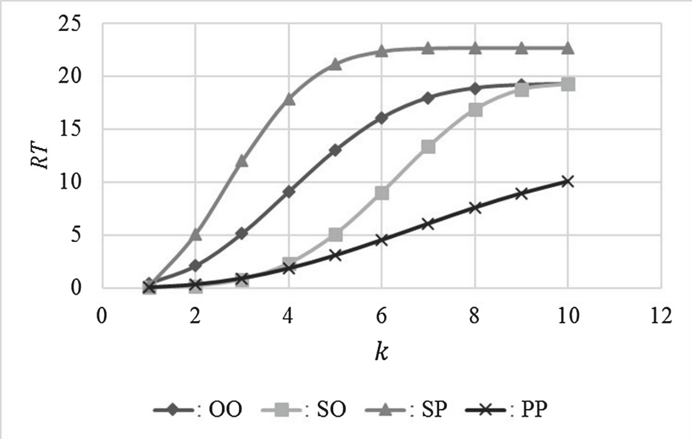

Fig. 6. Expected delivery time the RT ($xr = 10$, LP type 2).

5 Concluding Remarks

Mobile nodes are interconnected in wireless networks. A node communicates with another node in the communication range. A node consumes energy to transmit messages in the buffer. In this paper, we proposed the algorithm to retransmit messages where inter-retransmission intervals of the messages are changed depending on the types of nodes. In the evaluation, we showed the expected number of retransmissions and expected delivery time of messages.

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