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NODE DENSITY IMPACT ON ENERGY CONSUMPTION AND CONTACT PROBABILITY OF OPPORTUNISTIC NETWORK

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ABSTRACT

Opportunistic communication between two encountered nodes is commonly established using a radio technology, such as Wi-Fi or Bluetooth. One issue involved in opportunistic communication is a trade-off between connection time and probability of resource consumption. This paper presents a comprehensive study on density analysis for decentralized distributed opportunistic communication using Wi-Fi technology. In this work, study and analysis of contact probability and energy efficiency of variant density in a particular area are performed. The contribution of this work is the analysis of the impact of density on the connection probability and resources, as well as a simulation study framework to analyze the contact event with a view of energy consumption. The study gave detailed contact information, such as contact probability based on node density and transmission range in a particular area, as well as the beacon exchange process as an element of channel utilization and energy consumption. The influence evaluation of various parameters on each other and finally on the system performance is also presented.

KEYWORDS

Opportunistic Communication, Contact Probability, Beacon Interval, Energy Consumption, Node Density.

1. INTRODUCTION

The opportunistic network typically consists of a large number of devices deployed over a particular area. Opportunistic nodes are capable of exchanging messages with the surrounding environment. This opportunistic environment has no stable end-to-end connectivity. The relay nodes perform the store and carry message to transfer it to the destination. However, in a sparse opportunistic network, the distance between neighbouring nodes is usually bigger than the interface transmission range. Thus, multi-hop forward or routing is unfeasible due to lack of end-to-end connectivity. Message transmission in opportunistic networks is accomplished through hop-by-hop routing. Also, opportunistic nodes have different mobility patterns that vary from deterministic to completely random mobility pattern. The main challenge of spares opportunistic networks is the time of contact together with the energy efficiency of neighbour discovery and message replication. Mobile opportunistic nodes have to discover the neighbours or forwarders in the transmission area. Ideally, each mobile node should be able to discover the next hop to reduce delay and avoid possible message losses at the local buffer of the node in message transmission. Moreover, the mobile opportunistic node discovery process should exploit as much short time available for message exchange and replication as possible. Due to limited energy resources, the discovery process is made difficult by mobile nodes energy constraints. Neighbour discovery is achieved through typical periodic listening or sensing when the node regularly sends a beacon to announce its presence in the area, while other nodes check for possible beacons. Hence, proper node definition ensures timely discovery of all contacts to reduce energy consumption at the mobile node, thus increasing node lifetime but decreasing the capability or delay of detecting contacts and neighbours. In general, to solve the message delivery problem, the opportunistic routing protocol uses broadcast mechanism for message delivery via Store-Carry-Forward fashion through the network. The simplest opportunistic routing protocol is flooding-based routing protocol named Epidemic [1]. In Epidemic routing protocol, the deliverable messages are broadcast to every encountered node that has no buffered copy of the message. The number of

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broadcasts or message copies increases through message dissemination process depending on node contact probability and number of neighbours. In addition, the number of message copies in the entire network is limited by the message Time-To-Live TTL and number of network nodes. This paper presents an analysis of the impact of density on contacts and energy. In Section 2, related work is presented. Section 3 discusses opportunistic communications and neighbour discovery for the mobile opportunistic network. The opportunistic communication impact by the network density is discussed in more detail. Section 4 discusses the trade-off between contact probability and energy consumption in mobile opportunistic networks. In Section 5, the metrics and tools used together with the data from different experiment scenarios are presented. The results obtained from experiment scenarios and simulation experiments are investigated and presented in Section 6. Finally, Section 7 gives the conclusion and future work.

2. RELATED WORK

The beacon interval is critical for wireless infrastructure and infrastructure-less opportunistic network communications. There is no specific value defined for beacon interval such as proposed in [2] which sets the beacon interval of the master device in infrastructure-based mobile opportunistic networks. In their work, they suggest the beacon interval to be twice the traditional interval of a commercial Wi-Fi appliance. Namely, the authors term their approach with Double Hundred Beacon Interval 2HKBI. In [3], the scenarios of access-point-based opportunistic network communications are proposed. The authors assume that the node scanning probe is equal to both passive and active scanning times. They also calculate the epidemic dissemination speed regarding the beacon rate in a time slot of one second. Many routing protocols with their benefits have been proposed for opportunistic networks. Commonly, the well-known opportunistic routing protocols do not consider the available energy budget when making routing decisions. Only few researchers have investigated energy-aware protocols. The performance of opportunistic routing protocols which are epidemic are evaluated in [4]. Spray & Wait, PROPHET, MaxProp and Bubble Rap used the ONE simulator presented in [5]. Their analysis show that the most effective routing protocol is using metrics such as delivery ratio/latency and energy consumption. The results illustrate the impact of energy consumption on the routing performance. Other related studies have been conducted in order to evaluate the performance of opportunistic routing protocols under resource constraints. These works proposed Markovian Chain model to address the energy problem in Delay Tolerant Networks DTNs. As an example, in [6], the issue of energy consumption opportunistic forwarding for DTNs by introducing a Markov model and proposed different types of forwarding strategies is considered. Furthermore, the authors in [7] proposed their Energy-Aware Epidemic Routing (EAER), which is an extension of the n-Epidemic routing proposed in [8], which aims to improve the performance in terms of message delivery ratio and energy consumption. The n-parameter policy is proposed for optimizing the possibility of message transmission from a node to its neighbours, known as node degree. By using this strategy, a node will forward its message to the next node only when it is in the range of at least n neighbours as a threshold of message transmission. Furthermore, [12] proposes a routing algorithm which reduces energy consumption and increases delivery probability. The authors achieved this by calculating nodes' remaining energy and available free buffer space for receiving copies of messages. In [13], the authors analyzed the social network model based on a multi-layer detected by encounters of the nodes. Moreover, this paper investigates the relationship between different layers in terms of node degree and population. The authors of [14], suggest an Energy Aware EA-PRoPHET as a new protocol. This protocol considers the limitation of energy budget and physical buffer space for message replication process. The paper shows the simulated results of the suggested protocol, which say that it has better performance. [15] describes the mobility traces based on a campus environment to capture the contacts using Bluetooth. The authors gathered the information based on the Facebook relationships. Their contribution was a way of understanding the human mobility at different social ties.

3. DENSITY IMPACT ON BEACON AND CONTACT

Opportunistic mobile nodes detect whether there is any neighbour device to communicate; i.e., a device that needs to send beacons (active mode) or listen to beacons (passive mode). This task is costly in terms of energy, bandwidth and delay. Due to different mobility models, the network is divided into different groups. However, discussing such a complex situation is useful for routing protocol design when considering the number of infected nodes in each group that impacts the dissemination speed. Both infrastructure and infrastructure-less opportunistic networks have periodically broadcast their identifiers that can be seen by any Wi-Fi-enabled nodes as control signalling (Beacon). Wi-Fi-enabled nodes typically listen to these announcements in regular intervals. In order to set up a connection, a node must initiate a connection and the other node must accept the connection. Therefore, as contact probe process, the beacon will consume the bandwidth of the radio channel. Furthermore, it consumes the energy resources of the nodes. The beacon interval will have an impact on the contact probability as one hop detection delay of neighbour discovery. The beacon indicates why two encountered nodes disconnect from each other and when they have left the transmission range. The beacon is kept alive signalling, where the transmission range and node density are yields to this event of disconnection, especially when the nodes of the network move in, particular area. The other important reason of the disconnection between encountered nodes is the energy limitation of the mobile opportunistic network. The mobile opportunistic node is suffering from resource limitation in terms of storage, bandwidth and energy. To improve the mechanism of neighbour discovery in a mobile opportunistic network environment, IP Neighbour Discovery (IPND) [9] is implemented and published by IETF in the Internet-Draft. IPND protocol is a method of mobile opportunistic communication for nodes to discover the existence, availability and addresses of encountered nodes as one hop connected. IPND periodically transmits UDP message (broadcast) and receives beacons as a distributed system.

4. Energy and Neighbour Discovery

The mobile opportunistic network has no reliable end-to-end connectivity, where it is hard to guarantee a stable path due to time-varying network topology. Thus, mobile opportunistic nodes have to replicate messages to relay nodes which are in their communication range. In order to enable such message replication, nodes have to continuously detect the environment to discover neighbour nodes. Obviously, this neighbour discovery is an extreme energy consumption. Therefore, it is important to investigate energy consumption during the contact and neighbour discovery process in the opportunistic network. One strategy for saving node energy is to increase the interval between beacon scans of contact and neighbour discovery. The consequence of this interval increase is that mobile opportunistic nodes may miss the opportunity to contact other nodes and thus opportunities to replicate the messages are lost. Moreover, if nodes scan the environment much frequently, a lot of energy will be consumed in the contact and neighbour discovery process causing it to be inefficient. This valuable reason points to a trade-off between energy consumption and contact or neighbour discovery delay, where the nodes scan their transmission range using the beacon broadcast process. For neighbour discovery which uses a constant contact scan interval, the larger the contact scan interval, the greater the number of missed contacts encountered and vice versa. The reflection of the trade-off between energy consumption and contact probability in opportunistic networks is investigated.

5. Tools and Metrics

5.1 Tools

The ONE simulator is used for simulating various movement models. These movements are generated by synthetic models or real movement models. Furthermore, the ONE simulator is able to forward or replace the messages between nodes through different opportunistic routing protocols. The ONE simulator has four modules; namely, movement, routing, event and report models.

5.1.1 Energy Model

In designing an opportunistic routing scheme, node energy needs to be taken into consideration. This fact reveals the importance of deeply analyzing the core design of routing protocols and message replication issues between encountered nodes. The routing and replication will depend on the energy budgets of both nodes. Therefore, in this work, an energy model for an opportunistic simulator is used. Based on this energy model, the energy efficiency of existing epidemic routing protocol that achieves higher message delivery rates through flooding replication decisions is studied. Furthermore, the available node energy is not considered in the majority of existing opportunistic routing protocols when they make forwarding or replication decisions. This limits both delivery probability of the message and the network lifetime. The trade-off between energy consumption and epidemic replication efficiency as a dynamic energy optimal control problem is also analyzed. In this scenario, each node decides on its replication probability based on its current energy budget. Since energy decreases with transmissions and receptions of messages, the replication decisions vary with time. Therefore, the replication decision is considered as a criterion to control the evolution of a network that captures the fraction of nodes carrying the copy of the message and the energy budget of the nodes. Each node in our energy model has an energy resource. The energy model which monitors consumed energy for node activities such as replication, transmission or message reception is integrated. Contact and neighbour discovery scanning, the energy model is implemented in the ONE simulator to analyze the impact of energy efficiency of the epidemic routing and IPND discovery protocols. This energy module considers scanning, reception and transmission interface states. To reflect different network density situations, we consider the three scenarios listed as parameters in Table 1 and compare their impact on node density. The comparison regards the different metrics under different radio ranges and node numbers in a particular area. The different three scenarios were simulated with the default settings of the ONE Simulator [5], [10].

5.1.2 Density and Contact Probability

Opportunistic nodes communicate with multiple hops in a store, carry and forward fashion. When a node cannot find any neighbour nodes within its communication range, it should gain a contact opportunity with encountered nodes to replicate the message. The contact is a criterion of finding suitable nodes which can replicate the message to the destination. Clearly, the node with a higher contact probability has a higher priority for replicating the message towards the destination.

Table 1. Simulation settings.

No.	**Settings**	**Map of downtown Helsinki, Finland**
1	Simulation time	12 h
2	Number of nodes	60,120,240
3	Group type with speed	Pedestrians (0.5-1.5 km/h) Cars (10-80 km/h) Trains (10-80 km/h)
4	Simulation area	Helsinki, Finland map (4500m , 3400m)
5	Routing protocols	Epidemic
6	Interface type	High speed
7	Transmission range	50,100,150,200,250 m
8	Bandwidth	250 KBps ,10 M
9	Buffer management	FIFO
10	Message size	0.5-1 MB
11	Message creation interval	25-35 s
12	Time-to-live (TTL)	300 min
13	Default buffer size	Pedestrians: 5 MB Cars, trains: 50 MB
14	Mobility model	Pedestrians: Shortest path map based Cars, trains: Map route

Moreover, the higher the node degree, the more likely to act as a relay based on popularity metric. Contact probability and node degree are exploited in existing replication schemes. Essentially, contact probability is an important factor for message replication process of the epidemic to the destination. This contact probability is impacted by transmission range and number of nodes. Furthermore, the node degree has an importance in opportunistic network analysis. The degree of the node indicates the number of nodes connected to this node. As a node's degree increases, it has a chance of contacting with other nodes in the network, the destination may be one of them.

5.2 Metrics

For the simulation scenarios of mobile opportunistic communication, the density has an impact on the contact probability and the energy consumption. It also has an impact on the available bandwidth. Therefore, we will measure these metrics for the analysis of contact and energy impact by node density.

5.2.1 Contact Probability and Delivery Latency

Two types of latency component simulation scenarios are considered. These are neighbour discovery delay and message transmission delay. Latency is relevant to node density as a component of nodes and transmission range. We further assume that all nodes are cooperative; therefore, they assign the available buffer space across the whole network of N nodes. The expected latency of delivered messages based on the number of message copies can be written as follows:

$$E(t)_{latency} = \frac{1-\exp(-TTLN\lambda_c)}{\lambda_c} \qquad (1)$$

where TTL is the message remaining lifetime, c is the Inter-Contact Rate which is the inverse of the average elapsed time of last encounter time for all nodes. The probability of contacts by capturing the number of contacts per hour in different node densities is calculated. We will consider the contact event as the minimum contact C_{min} which is calculated when the transmission range r is equal to one meter. The probability of contact C_{Prob} is calculated as the ratio of maximum contacts of the network that consists of N sets of nodes as vertex and (N-1) of outgoing edges for directed graph G(V, E) by the following equation:

$$C_{prob} = \frac{C_{hour}}{N^2 - N} \qquad (2)$$

Equation (2) shows that the contact probability C_{Prob} of the mobile opportunistic network is mostly impacted by the transmission range r regardless of the number of nodes N, where the value of (N^2-N) is assumed as a constant value in the same scenario of each different transmission range r.

5.2.2 Bandwidth and Message Transmission

This metric is conducted with flooding-based DTN routing protocol termed as the greedy uncontrolled epidemic routing protocol. Epidemic routing protocol is evaluated with different number of nodes and radio range. Where the epidemic routing protocol dissemination speed will be impacted by contact probability, contact probability is a function of the number of nodes and transmission range in the bounded area. The routing performance, impacted by node density considered, because node density has a higher impact on the buffer and routing performances. Obviously, the buffer and routing performances are based on the overhead variables which are replication counter and hop counter of the message. The main performance factor is the relayed, successfully transmitted, messages as a metric for resource consumption in terms of bandwidth and channel utilization.

5.2.3 Energy Consumption

Energy consumption is critical in an opportunistic environment. Therefore, we calculated energy consumption of receiving the management traffic. We consider that active scanning in opportunistic communication requires the transmission of requests and adds more energy consumption. The transmission beaconing as UDP message of IPND protocol with 5 second period of interval B_{int} and its energy E_b will be considered. In addition, contact duration C_{dur} will also be considered. Our energy model will conduct different interface states as Send, Receive, Scan states. The energy consumption by beacon in the IPND protocol will be calculated with the following equation:

$$E_B = \sum_{i=1}^{N} \frac{C_{dur}}{B_{\text{int}}} E_b \qquad (3)$$

6. NUMERICAL RESULTS

In this work, three different scenarios are applied for the comparison of node density impact on the epidemic performance. As a routing metric, we look at the end-to-end average delay. This delay or latency metric is used as a performance metric for different DTN applications. Figure 1 shows that epidemic router has a lower delay when the transmission range r is increased by 50 meters for every experiment. This is because the buffer criterion is based on FIFO, so that messages with high buffer delay will be removed. Furthermore, the buffer times have the highest impact on the message TTL, because high buffered messages are either dropped by full buffer space or expired TTL. The delay will be decreased by increasing the transmission range r. As in Figure 1, latency decreases by 500 sec until the range reaches 200 meters. At 250 meter range, latency stays stable,

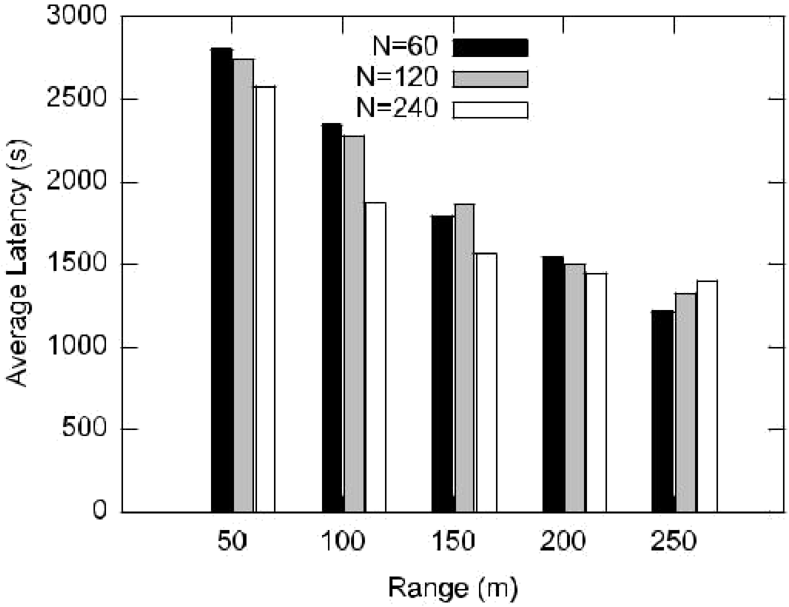

Figure 1 Average latency versus range.

contact probability influence is one of various parameters that have been evaluated. Figure 2 shows that contact probability increases as transmission range increases. Moreover, it shows that the minimum contact probability for different scenarios is achieved when the transmission range is equal to 50 meters. The minimum contact probability of spares network is 0.25. Figure 2 shows that this value is equal for the three scenarios, regardless of the number of nodes. This means that link availability of the three scenarios is equal regardless of the node density values.

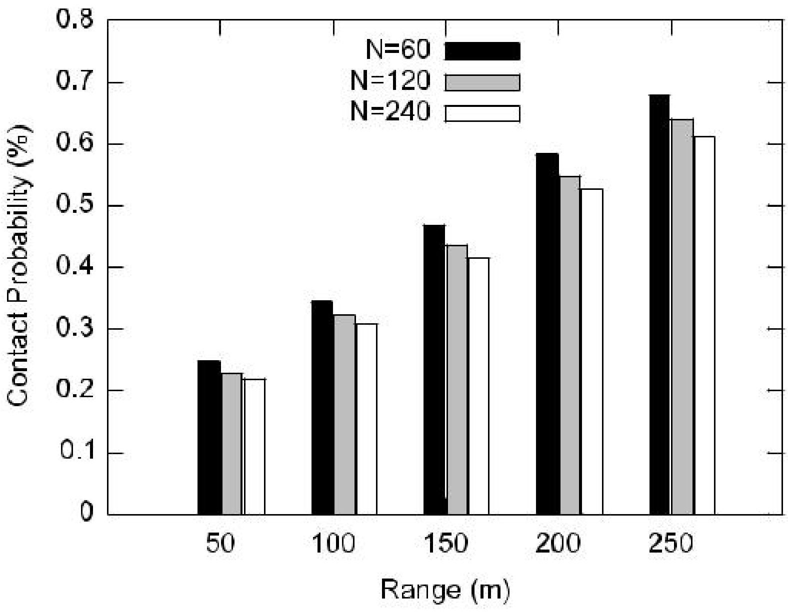

Figure 2. Contact probability versus the range.

To evaluate the epidemic performance with a variety of different node densities, it is also important to measure the relayed or successfully transmitted messages. Figure 3 shows that the number of message copies increases proportionally to the transmission range r and strongly with the number of nodes N. When increasing the number of nodes, the traffic sources of the whole network increase. In addition, the dissemination speed increases by increasing the number of nodes.

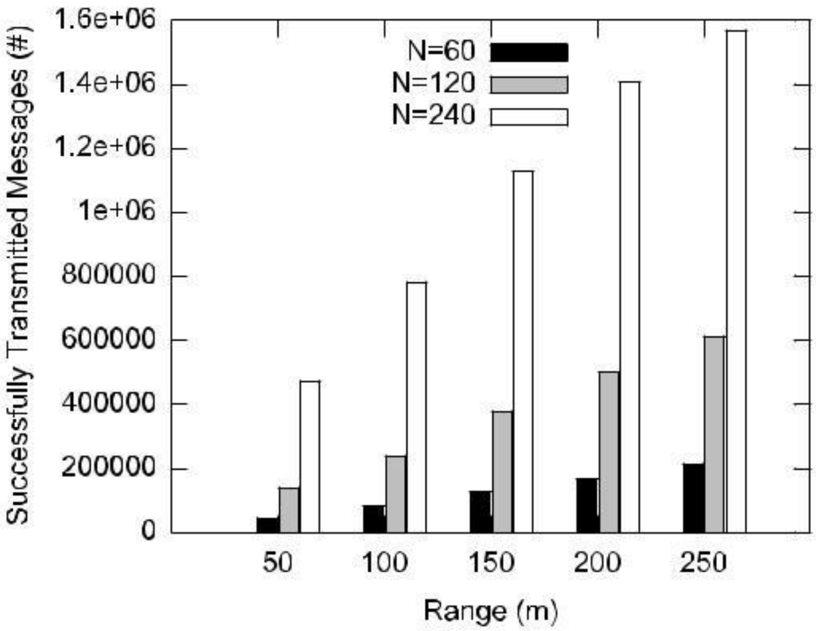

Figure 3. Successfully transmitted messages.

We provide simple energy efficiency. All nodes have an energy model that has the same network constant energy resource as Scan = 1126mW, Send = 1630mW and Receive = 1378mW, with equal values of different states considered in all scenarios. The whole network energy considered for different scenarios is 10^4 Wh. This value of energy guarantees that all nodes will always be on charge. Therefore, node communication interfaces are enabled. The IPND interval is selected as the default value of IPND beacon of IBR-DTN [11] of 5 seconds. Figure 4 shows the energy resource for all nodes after every experiment over simulation time. The Figure also shows the energy of the three different scenarios of 5 second IPND beacon. At 50 meter transmission range, Figure 4 shows that energy consumption increases by 5 % whereas, density is duplicated. The increment in energy consumption becomes 10% when the transmission range equals 250 meter. This is because the epidemic dissemination speed increases as the transmission range increases. Therefore, at a higher number of copies generated by the epidemic router, regarding the scenario of N = 240, we found that the increment of energy consumption was duplicated compared to the scenario of N = 120 nodes. Furthermore, the scenario of N = 60 nodes, which has minimum variety with respect to x-axis, has minimum slope compared with other scenarios. This comes from the fact that low density, low range and low number of nodes give priority to achieving the desired delivery with low energy consumption. From Figure 4, the energy of the network is improved by 10% when the node density is changed at a transmission range of 250 meters. This improvement comes from the fact that when the node density increases, the node degree increases. This is turn leads to improvements in connectivity and contact probability. Therefore, the percentage of delivery increases with short paths.

7. CONCLUSIONS

This paper addresses the problem of mobile opportunistic communication and neighbour discovery using Wi-Fi technology. In this work, we show that energy and bandwidth efficiency of opportunistic communication can be significantly improved. Furthermore, the performance analysis model used to analyze contact and energy of distributed opportunistic communication with different node densities is presented. The performance of epidemic routing with energy consumption, from the aspects of routing

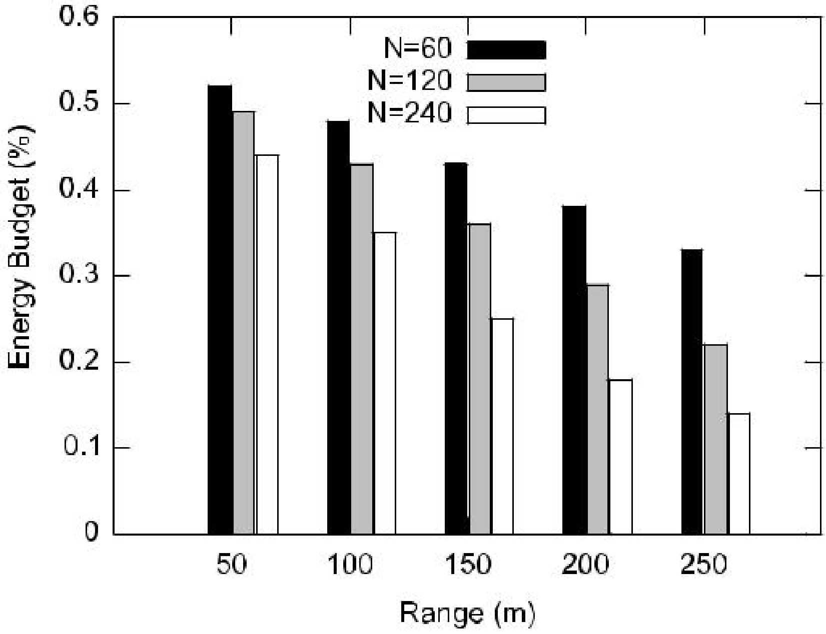

Figure 4. Energy consumption.

metrics in terms of message delivery delay and energy cost as both beacons and relayed messages, is also evaluated. The important parameters in our evaluation include contact probability and energy constraint of a neighbour discovery protocol (IPND). The network density is considered as a function of the number of nodes in the network, in addition to the node transmission range of a particular area. Investigating the impact of dynamic beacons approach on the efficiency of mobile opportunistic communication can be considered as future work for research in this field.

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ملخص البحث:

يتأسس الاتصال الانتهازي بين غقدتين متواجهتين في العادة باستخدام إحدى تقنيات الراديو مثل "واي فاي" أو "بلوتوث". وتتمثل إحدى القضايا المتعلقة بالاتصال الانتهازي في التسوية بين زمن الاتصال واحتمالية استهلاك الموارد.

تقدم هذه الورقة دراسة شاملة لتحليل الكثافة بالنسبة للاتصال الانتهازي الموزَع اللامركزي باستخدام تقنية "واي فاي". وفي هذا العمل، تمت دراسة وتحليل احتمالية الاتصال وفعالية الطاقة بتغير الكثافة في منطقة معينة. وتتمثل مساهمة هذا البحث في تحليل أثر الكثافة في احتمالية الاتصال وفي استهلاك الموارد، إلى جانب إطارٍ لدراسة محاكاة لتحليل حدث الاتصال من منظور استهلاك الطاقة.

وتعطي هذه الدراسة معلومات مفصلة عن الاتصال، مثل احتمالية الاتصال بناءً على كثافة العُقد ومدى الإرسال في منطقة معينة، إلى جانب عملية تبادل "المرشدات" كعنصر من عناصر الاستفادة من القناة واستهلاك الطاقة. كما تقدم الدراسة تقييماً لأثر متغيرات متنوعة في بعضها البعض وفي أداء النظام.