Feedback Pricing and Routing in Multi-hop Cellular Networks

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Abstract

Discovering an available relaying path for mobile nodes is a critical issue in research of multi-hop cellular networks. In this paper, we propose a Quality of Relay (QoR)-based pricing scheme to determine the price of the feedback incentives for intermediate nodes in a relaying path. Then, we present a routing scheme to select a relaying path based on the QoR value of each intermediate node in the path. Simulation results indicate that the QoR-based pricing scheme results in higher service availability than the fixed-rate pricing scheme under different relationships between price of feedback and willingness of forwarding packets. Moreover, the proposed QoR-based routing scheme causes a lower new call blocking probability than the shortest-path routing scheme.

Keywords**:** Feedback pricing, Routing scheme, Multi-hop cellular networks

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1. Introduction

Multi-hop cellular networks (MCNs) have been proposed to preserve the advantage of traditional single-hop cellular networks with multi-hop ad hoc relaying networks in recent years [11]. In the hybrid networks, the communication between the mobile node and the base station is relayed by a number of other mobile nodes. Since forwarding data for others incurs the consumption of battery energy and the delay of its own data, the assumption of spontaneous willingness to relay data is unrealistic for autonomous mobile nodes [7]. Some research has described how to stimulate intermediate nodes to forward data packets in multi-hop networks. Most works focus on its protocol and security aspects or just employ fixed-rate pricing on number of packets or volume of traffic forwarded. The major advantage of the fixed-rate pricing scheme is that billing and accounting processes are simple. However, such approach cannot react effectively to the individual impact of each mobile node on service availability of the multi-hop cellular networks.

In this paper, we propose a Quality of Relay (QoR)-based incentive pricing scheme to encourage collaboration based on the degree of the mobile nodes contributing to successful hop-by-hop connections. The proposed pricing scheme gives more incentives to the nodes that affect more relaying connections so that the service availability can be enhanced. Then, we present a new routing scheme to select the relaying path based on the QoR value of each intermediate node in the path. The proposed routing scheme can retain more valuable resource for later relaying requests, thereby accepting more relaying connections. Simulation results indicate that the proposed QoR-based incentive pricing scheme results in higher service availability than the fixed-rate pricing scheme under different relationships between price of feedback and willingness of forwarding packets. Moreover, the proposed QoR-based routing scheme causes a lower new call blocking probability than the shortest-path routing scheme under a certain constraint on maximum relaying capacity.

The rest of this paper is organized as follows. In section 2, we review the existing multi-hop cellular network models, incentive schemes for packets forwarding and routing schemes in multi-hop cellular networks. Section 3 describes the detail of the proposed QoR-based pricing and routing scheme. Section 4 presents the simulation results and discussions. Finally, concluding remarks are recommended in section 5.

2. Literature Review

More and more research focuses on integrating the cellular and multi-hop network models to leverage the advantages of each other, for instance, Opportunity Driven Multiple Access (ODMA) [17], Ad Hoc GSM (A-GSM) [1], iCAR [16], Mobile-Assisted Data Forwarding (MADF) [22], Unified Cellular and Ad-Hoc Network (UCAN) [12], …*etc*. The complete surveys of architectures and economic issues for MCNs are provided by two recent articles [11,13].

The approaches of incentive schemes in pure ad hoc or hybrid ad hoc networks can be classified into detection-based and motivation-based. The motivation-based approach provides incentives to foster positive cooperation in ad hoc networks. Buttyán *et al*. use a virtual currency called nuglets as incentives given to cooperative nodes in every transmission [3]. The proposed models do not discuss the number of nuglets should be rewarded to the intermediate nodes. Buttyán *et al*. also propose a mechanism based on credit counter to stimulate packet forwarding [4]. The number of feedback nuglets depends on the number of forwarding packets in this method. In [8], Jakobsson *et al*. suggest that packet originators associate subjective reward levels with packets according to the importance of the packet. Lamparter *et al*. propose a charging scheme based on volume-based pricing models [10]. In [20], the authors propose an incentive mechanism based on the packet size.

The existing multi-hop routing protocols can be generally classified into table-driven and on-demand [2,18,19]. In table-driven routing protocols, such as Destination-Sequenced Distance-Vector (DSDV) [14], all mobile nodes maintain one or more tables to keep information on how to reach all possible destinations in the networks. In on-demand routing protocols, such as Dynamic Source Routing (DSR) [9] and Ad hoc On Demand Distance Vector (AODV) [15], the routes are established based on demand by the source. The common approach in most routing protocols is to consider the shortest-path routing. However, routing packets according to minimum hop count may route almost packets over a few (shortest-distance) paths in the networks [21].

3. QoR-based Feedback Pricing and Routing

3.1 Supply Function for Providing Relaying Services

The price of the incentives can affect the motivation of mobile nodes providing relaying services and is usually characterized by a supply function that represents the reaction of mobile nodes to the change of the price [6]. The general supply function describes that the producers are willing to produce more goods as the price goes up. Because mobile nodes have different degrees of sensitivity to price, here we consider three forms for the supply function as follows [5]:

$$S_1: \quad p_v / p_{\max} \quad , \quad 0 \le p_v \le p_{\max} , \tag{1}$$

$$S_2: \quad S(p_v) = \begin{cases} \dfrac{e^{-(p_{\max}/p_v - 1)^2}}{(P_{\max}/P_v)} & when \quad 0 < p_v \le p_{\max} , \\ 0 & when \quad p_v = 0, \end{cases} \tag{2}$$

$$S_3: \quad S(p_v) = \begin{cases} \dfrac{1}{(p_{\max}/p_v - 1)^4 + 1} & when \quad 0 < p_v \le p_{\max} , \\ 0 & when \quad p_v = 0, \end{cases} \tag{3}$$

where $p_{\max}$ is the maximum price that network provider can feedback, p_v is the price of the feedback incentives for node v per unit of relay data. $S(p_v)$ denotes the possibility of node v accepting the price to forward data packets.

3.2 Proposed QoR-based Incentive Pricing Scheme

In this paper, we focus only on a single base-station cell as indicated in Fig. 1. Let M_x be the set of intermediate nodes in the path from node x to the base station, then the path availability between node x and the base station, PA_x, is defined as follows:

$$PA_x = \prod_{v \in M_x} S(p_v) \,. \tag{4}$$

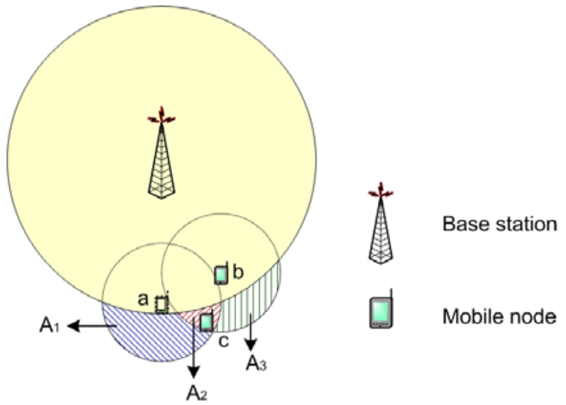


Figure 1 An example of multi-hop cellular networks with a single base-station

Since networking services provided by the base station are available for the mobile nodes outside the coverage of the base station when the mobile nodes can set up a hop-by-hop connection to the base station successfully, we define the service availability of the relaying networks as the probability that a mobile node outside the coverage of the base station can connect to the base station.

In order to evaluate the degree of a mobile node contributing to the service availability of the multi-hop cellular networks, we introduce a new metric called Quality of Relay (QoR) as follows:

$$QoR_v = \sum_{i \in C_v} \frac{1}{RI_i} \,. \tag{5}$$

where C_v is the set of positions inside the coverage of the node v where the mobile node requires hop-by-hop connections to reach the base station, RI_i is the relay index (RI) of position i that is defined to be the number of mobile nodes capable of relaying traffic for a mobile node staying in position i. As the example indicated in Fig. 1, $RI_{i \in A_1} = 1$ because only node a can relay data for the mobile nodes reside in area A_1; $RI_{i \in A_2} = 2$ because both node a and node b can relay data for the mobile nodes reside in area A_2. Let $NP(A_1)$, $NP(A_2)$ and $NP(A_3)$ be the number of positions belonging to A_1, A_2 and A_3, respectively, the degrees of node a and node b contributing to the service availability of networks are evaluated by their QoR values as follows:

$$QoR_a = \sum_{i \in C_a} \frac{1}{RI_i} = \sum_{i \in (A_1 \cup A_2)} \frac{1}{RI_i} = (NP(A_1) * \frac{1}{RI_{i \in A_1}}) + (NP(A_2) * \frac{1}{RI_{i \in A_2}}) = NP(A_1) * \frac{1}{1} + NP(A_2) * \frac{1}{2} \quad (6)$$

$$QoR_b = \sum_{i \in C_b} \frac{1}{RI_i} = \sum_{i \in (A_2 \cup A_3)} \frac{1}{RI_i} = (NP(A_2) * \frac{1}{RI_{i \in A_2}}) + (NP(A_3) * \frac{1}{RI_{i \in A_3}}) = NP(A_2) * \frac{1}{2} + NP(A_3) * \frac{1}{1} \quad (7)$$

From above equations, QoR_a is greater than QoR_b because the coverage of area A_1 is larger than that of area A_3. There are two conditions that node v has a higher QoR value:

- The node v has larger C_v, which means it can support larger coverage where mobile nodes necessitate hop-by-hop connections to reach the base station.
- The positions inside C_v have lower RI values, which means the mobile nodes inside C_v can be supported by fewer nodes. That is, the node v can provide relaying services to the mobile nodes that others cannot support.

Consequently, a node with a higher QoR value represents that it has more contributions to the relaying capability of the networks, so that its high willingness of forwarding data packets can enhance the service availability of the networks. Since the higher QoR value represents that the resource of the mobile node is more valuable, the base station should apply the QoR value of a mobile node as a reference to give incentives for increasing the willingness of providing relaying services.

Let N be the set of intermediate nodes capable of forwarding data for mobile nodes to reach the base station, $AQoR$ be the average QoR value of all nodes in N, that is,

$$AQoR = (\sum_{v \in N} QoR_v) / (\sum_{v \in N} 1). \quad (8)$$

Then, the proposed QoR-based incentive pricing scheme assigns the price of the feedback incentives for node v, p_v, as follows:

$$p_v = p_0 + (QoR_v - AQoR) * \frac{R_p}{R_{QoR}},$$

$$\text{where } R_p = \min\{p_0, p_{\max} - p_0\} \quad (9)$$

$$R_{QoR} = \max\{\max_{v\in N}\{QoR_v\} - AQoR, \ AQoR_v - \min_{v\in N}\{QoR_v\}\}$$

p_0 is the price adopted in the fixed-rate pricing method. The proposed scheme employs p_0 as a basic price and derives p_v according to the difference between QoR_v and $AQoR$. The parameter R_p / R_{QoR} aims to adjust p_v in the interval [0, $p_{\max}$].

3.3 Proposed QoR-based Routing Scheme

Limited capacity is a major problem in existing wireless networks, this makes only a limited number of connections can be built. Besides, forwarding data for others utilizes the resources of the mobile nodes such as battery energy, link bandwidth, buffer space and processing time. Consequently, the mobile nodes may accept only a certain number of relaying requests. In A-GSM system [1], a protocol parameter "relaying capacity" is used to tell others the number of calls a mobile node can simultaneously relay.

The proposed routing scheme selects a relaying path with minimum sum of the QoR values of all intermediate nodes in the path. Let IM_r be the set of intermediate nodes (the nodes in the route except the source and the destination) in route r, $TQoR_r$ be the sum of the QoR values of all intermediate nodes on the route r, that is,

$$TQoR_r = \sum_{v\in IM_r} QoR_v . \quad (10)$$

Let R_i be the set of routes from node i to the base station, we select the route with minimum $TQoR$ value as the relaying route for connecting node i to the base station. That is, the routing criteria is

$$\min_{r\in R_i}\{TQoR_r\} . \quad (11)$$

As the example illustrated in Fig. 1, node c has two choices for sending data to the base station: $c \to a \to BaseStation$, $c \to b \to BaseStation$. The $TQoR$ values of these two routes are as follows:

$$TQoR_{c\to a\to BaseStation} = QoR_a . \quad (12)$$

$$TQoR_{c \to b \to BaseStation} = QoR_b \,. \tag{13}$$

In our routing scheme, node c selects the relaying path $c \to b \to BaseStation$ because QoR_b is less than QoR_a. As the QoR value defined in previous section, the mobile node with a higher QoR value represents that its resource is more valuable. That is, it can support larger coverage or provide relaying services to the nodes that others cannot support. The proposed routing scheme selects a relaying path with minimum $TQoR$ value makes the valuable resource retain for later relaying connections or serves the mobile nodes that others cannot support.

4. Simulation Results and Discussions

The simulation environment is a rectangular region of size 400 units by 400 units with a single base station located in the central point. The radius of the base station is 150 units and the radius of each mobile node is 100 units. Each simulation runs for 100 seconds. The mobile nodes move according to a random waypoint model [9]. Each mobile node starts its journey from a random location to a random destination with a randomly chosen speed (uniformly distributed between 0-12 units/s). Once the destination is reached, another random destination is targeted after a 10-second pause time. The arrival of new data transmission requests initiating in each mobile node forms a Poisson process with rate $\lambda = 0.2$ calls/second and the data transmission times are exponentially distributed with mean 10 seconds.

4.1 QoR-based Pricing v.s. Fixed-rate Pricing

In this section, we compare the proposed QoR-based pricing scheme with the fixed-rate pricing scheme. For different number of mobile nodes randomly distributed in the rectangular region, the simulator computes the probability that a mobile node outside the coverage of the base station can connect to the base station successfully. Since no routing topology is pre-constructed in the networks, herein we assume the mobile nodes randomly select one of the neighboring nodes that have relaying paths to the base station. We adopt p_0 ($S(p_0) = 0.5, S(p_0) = 0.4$) as the fixed price in the fixed-rate pricing scheme and the basic price in the proposed pricing scheme. In Figs. 2 through 4, we observe that the QoR-based incentive pricing scheme results in higher service availability than the fixed-rate pricing scheme under various number of mobile nodes for different supply functions. According to Figs. 2 through 4, we summarize the percentage of improvement in service availability from the fixed-rate pricing scheme to the QoR-based pricing scheme for different supply functions in Table 1. Since relaying costs is one of major concerns for adopting multi-hop cellular networking model, we also list the percentage of increase in relaying costs per connection that are rewarded to the intermediate nodes in Table 1. The QoR-based pricing scheme results in higher relaying costs per connection than the fixed-rate pricing scheme. Because the

QoR-based pricing scheme gives more incentives to the nodes that affect more relaying connections to enhance service availability. However, the proposed scheme also decreases incentives for the node of low impact on relaying connections. Consequently, the increase in relaying costs is much lower than that in service availability.

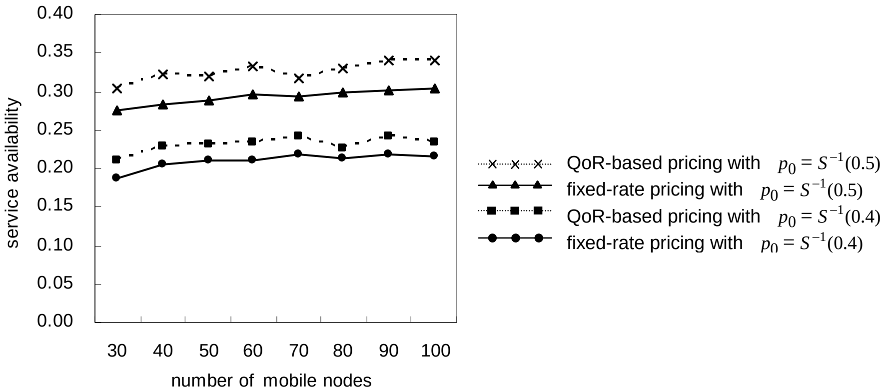


Figure 2　Comparison of service availability by fixed-rate pricing and QoR-based pricing under different number of mobile nodes with supply function S_1

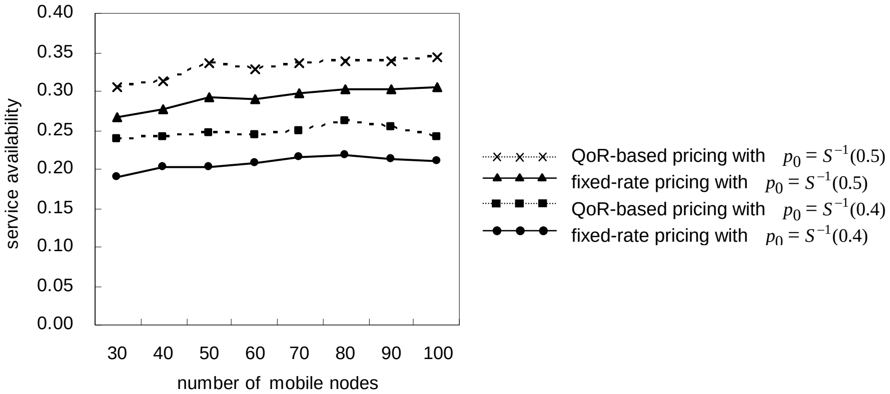


Figure 3　Comparison of service availability by fixed-rate pricing and QoR-based pricing under different number of mobile nodes with supply function S_2

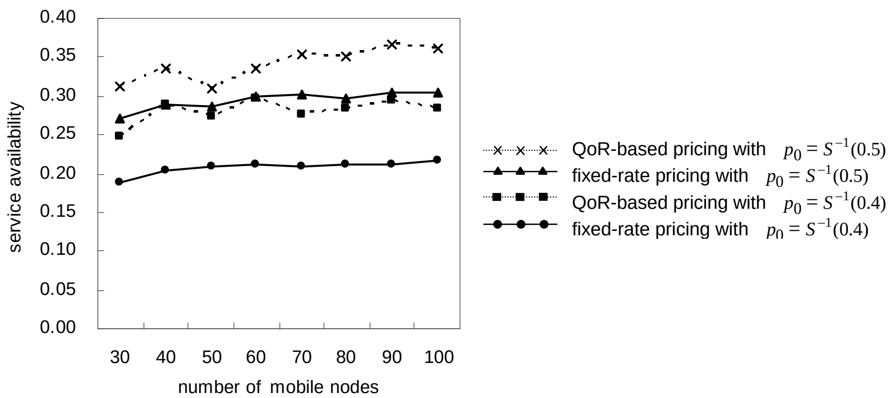


Figure 4　Comparison of service availability by fixed-rate pricing and QoR-based pricing under different number of mobile nodes with supply function S_3

Table 1 Percentage of increase in service availability and relaying costs per connection for different supply functions

	S_1		S_2		S_3	
	$p_0 = S^{-1}(0.4)$	$p_0 = S^{-1}(0.5)$	$p_0 = S^{-1}(0.4)$	$p_0 = S^{-1}(0.5)$	$p_0 = S^{-1}(0.4)$	$p_0 = S^{-1}(0.5)$
increase in service availability	10.05%	11.22%	19.13%	12.97%	34.76%	15.82%
increase in relaying costs	4.12%	4.39%	1.61%	1.18%	4.44%	4.62%

4.2 QoR-based Routing v.s. Shortest-path Routing

In order to observe the performance of different routing schemes under limited relaying resource, each mobile node only accepts a certain number of relaying requests. Herein the maximum relaying capacity for each mobile node is set as 4 or 6. In Figs. 5 through 7, we observe that the QoR-based routing scheme provides a lower new call blocking probability than the shortest-path routing scheme under various number of mobile nodes for different supply functions.

5 Conclusions

Service availability and relaying costs are two major concerns for adopting multi-hop cellular networking technology. In this paper, we present a QoR-based incentive pricing scheme to enhance service availability by adjusting the price of the feedback incentives based on the importance of the mobile nodes for providing relaying services. The proposed method increases incentives for nodes of high importance and decreases the incentives for node of low importance so that it enhances service availability with only a slight increase in relaying costs. Then, we also present a new routing scheme to select the relaying path depending on the QoR value of each intermediate mobile node in the path. The proposed routing scheme can retain more valuable resource for later relaying requests, thereby accepting more relaying connections. Simulation results indicate that the proposed QoR-based pricing scheme results in higher service availability than the fixed-rate pricing scheme. Moreover, the proposed QoR-based routing scheme causes a lower new call blocking probability than the shortest-path routing scheme under a certain constraint on maximum relaying capacity.

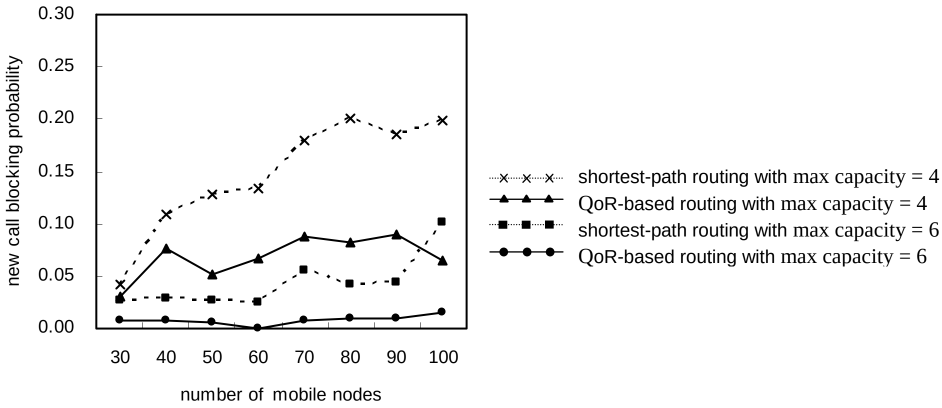


Figure 5 Comparison of new call blocking probability by QoR-based routing and shortest-path routing under different number of mobile nodes with supply function S_1

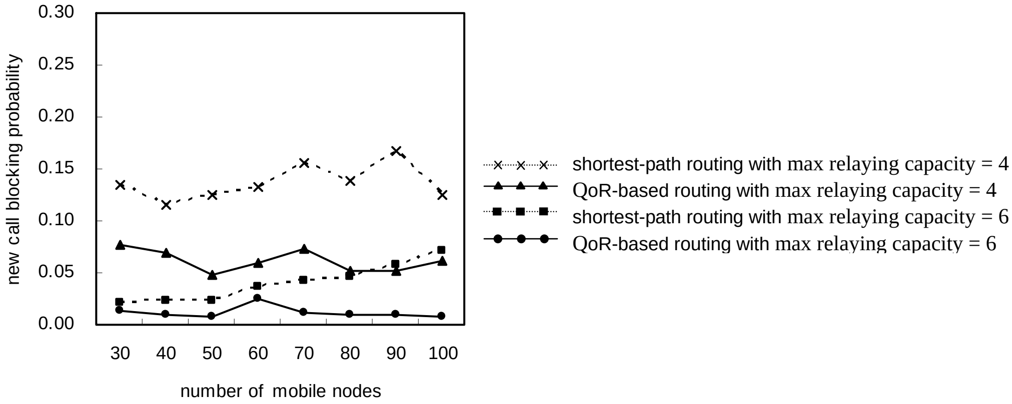
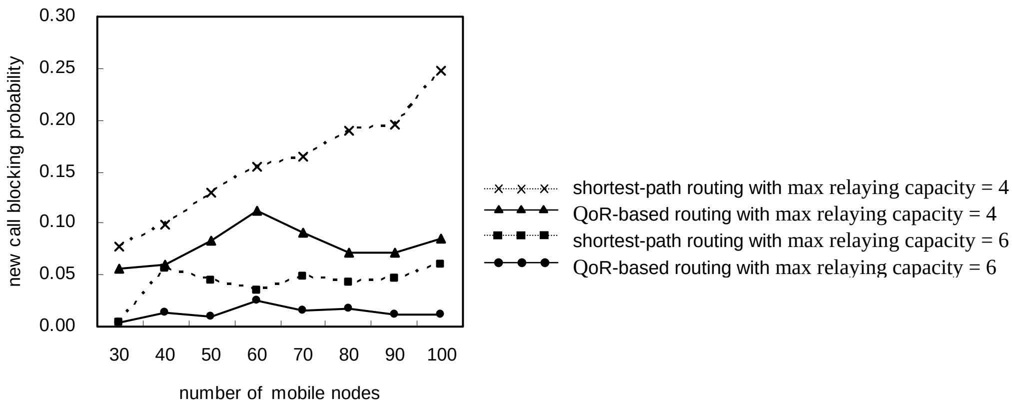


Figure 6 Comparison of new call blocking probability by QoR-based routing and shortest-path routing under different number of mobile nodes with supply function



S_2Figure 7 Comparison of new call blocking probability by QoR-based routing and shortest-path routing under different number of mobile nodes with supply function S_3

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