Performance Comparison of Mobile Support Strategies

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Abstract

This paper presents performance comparison among five strategies for mobile support. The major facilities that are required for a network protocol to support mobile hosts are location management and packet forwarding. Based on this observation, we consider five basic strategies which use distinct methods to achieve these facilities and compare their performance. These five strategies are Broadcast Notification (BN), Broadcast Forwarding (BF), Broadcast Query (BQ), Default Forwarding (DF), and Default Query (DQ). As a result of analytical evaluation and comparison, it is shown that under different network conditions, such as number of routers, network topology, migration/communication ratio, data/control packet size ratio, different strategies produce minimum network traffic. In short, DF and DQ show the best performance in scalability, while BF and BQ are efficient for frequent migration. On the other hand, BN is suitable for a small network which has hosts with rare migration.

1 Introduction

In order to realize mobile communication in computer networks, two kinds of transparency are required: *operational transparency* and *performance transparency* [6]. The operational transparency means that mobile users can continuously access to network services without being forced to operate any additional procedures during or after their migration. The performance transparency, on the other hand, means that mobile users can use the network services with similar performance to the performance they can experience when they use the services from a fixed location. Focusing on the operational transparency, a number of mobile host protocols have been proposed [1], [3], [5], [7], [8], [9], [10], [11], whereas performance transparency has not yet been fully discussed.

Performance transparency can be achieved through efficient use of network resources such as network bandwidth. Notice that there are two basic functions that are essential to mobility support: *location management* and *packet forwarding.* The efficient use of network bandwidth is significantly affected by these functions, since control packet to exchange the location information and data packet routed via non-optimal path produce large traffic. Hence, performance evaluation can be investigated through the observation on the network traffic produced by these two functions.

We can consider several distinct strategies based on how to implement these functions. For example, one possible solution for location management is that the router sends a notification packet to all other routers when the router detects a new mobile host. Another possible solution is that the router sends the packet to a particular router insted of all routers. Consequently, we have five basic strategies for mobile support: Broadcast Notification (BN), Broadcast Forwarding (BF), Broadcast Query (BQ), Default Forwarding (DF) and Default Query (DQ). Although the existing proposals have difference in details, they can be categorized into these basic strategies. Unlike the approach in [6] which compares mobile host protocols directly, we compare these basic strategies. Therefore, the fundamental characteristics concerning the performance can be observed more clearly.

As a result of analytical evaluation and comparison, it is shown that under different network conditions, such as number of routers, network topology, migration/communication ratio, data/control packet size ratio, different strategies produce minimum net-

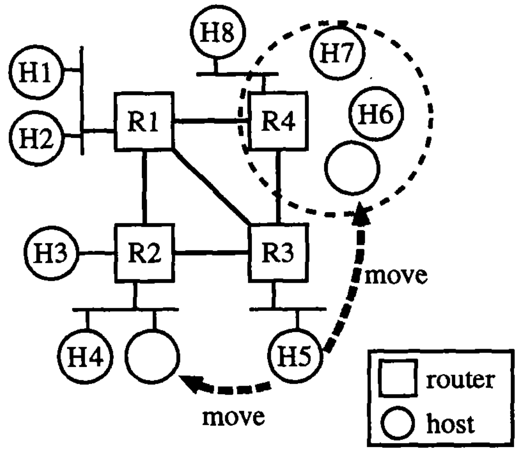

Figure 1: Example of network configuration.

work traffic. In short, DF and DQ show the best performance in scalability, while BF and BQ are efficient for frequent migration. On the other hand, BN is suitable for a small network which has hosts with rare migration.

In section 2, the network model and the five strategies are briefly described. In section 3, we first analyze the traffic of each strategy, and then compare them using two example network topologies. We also discuss the performance comparison in general topology networks. Finally, we conclude the paper and state future work in section 4.

2 Mobile Support Strategies

Consider a simple network model as shown in Figure 1. Routers are connected to each other via wired links. They may have wireless interface as well as wired interface. In this model, all hosts can potentially be mobile hosts, because they can move freely from one subnetwork to another. For example, host H5 can move to the subnetwork on which router R2 resides, and into the wireless cell of router R4 if it has a wireless interface.

A mobile host is served by at least one router which handles the data packets from/to the mobile host. We refer the router as current router. In some cases, there is another router which has different role for serving the mobile host. We refer the router as default router, which is responsible for advertising the location of the mobile host. Note that this location is not always the current location. The default router may advertise the fixed location which will not change despite the migration. Of course, in some cases, one router acts as both default router and current router.

The current router may choose to send a notification packet to all routers, the default router or even no router, when it detects a new mobile host. The notification packet includes the new location information of the mobile host. In the latter two cases, on receiving a data packet destined to the mobile host, the router must select the way of forwarding packets. One way is that the router forwards the packet to the default router, and the alternative is that the router sends a query packet to the default router so that it can get the current location to be used for forwarding.

Consequently, we have five basic strategies as described below:

1. Broadcast Notification (BN)

   In a link state routing protocol like IS-IS protocol [4], whenever a router detects a new mobile host, it becomes the default router and broadcasts a notification packet, which includes the current location of the the mobile host, to all the other routers in the same network. In this case, the default router is also the current router at the same time. The previous default router also broadcasts a notification packet to all the other routers to let them know that it is no longer the default router. Since a router learns a new location whenever a host moves, it can forward data packets to the current location using the optimal path.

2. Default Forwarding (DF)

   In DF, having detected a new mobile host, a router becomes the current router and sends a notification packet only to the default router, which will be acknowledged with a confirmation packet from the default router. If a router receives a data packet to the mobile host, it forwards the packet to the default router, since the default router always advertises the fixed location of the mobile host. The data packets are then forwarded by the default router to the current router.

3. Default Query (DQ) There is similarity between DQ and DF concerning the way of migration notification, though there is a little difference in the way of forwarding packets. Since the current router sends a notification packet only to the default router, a router receiving a data packet needs to get the current location before it forwards the packet. This is done by sending a query packet to the default router. After that the router forwards the packet using the same optimal path as used in BN.

4. Broadcast Query (BQ)

   We have already discussed the cases in which the current router sends a notification packet to either all routers or the default router when a mobile host moves. We then consider how a router

Table 1: Strategies used in mobile support protocols.

Mobile Protocols	Broadcast Notification	Broadcast Forwarding	Broadcast Query	Default Forwarding	Default Query
Carlberg [1]	○				
Ioannidis et al. [3]			○		
IS-IS protocol [4]	○				
Mobile IP [5]				○	
Perkins and Bhagwat [7]				○	
Tanaka and Tsukamoto [8], [10]	○			○	
Teraoka et al. [9]				○	
Wada et al. [11]				○	

can forward a data packet when it does not know neither the current location nor the default router of the mobile host. In such case, one choice the router can select is to ask all routers where the mobile host is. It broadcasts a query packet to all routers and waits a response from the current router. After learning the current location of the mobile host, the router forwards the data packet.

5. Broadcast Forwarding (BF)

   The alternative way is to forward the data packet to all routers instead of sending a query packet. The current router intercepts the packet and passes it to the mobile host, while the other routers merely discard it.

Table 1 shows which strategy is used in the existing proposals. Almost all protocols use only one strategy, while our proposals use two strategies. They discuss the improvement in performance by using two strategies in a hybrid way [8]. Although BF is not used in these protocols, it has been widely used in packet radio networks to support communication between hosts whose locations are not known beforehand [2]. To our knowledge, DQ is not used in mobile support protocols.

3 Performance Evaluation

3.1 Traffic Analysis

Among many factors that affect performance transparency, we use network traffic as performance measure. The traffic produced by each strategy can be calculated by packet size $\times$ hop count.

We define several parameters relevant to the network configuration:

- N : Total number of routers.
- L : Total number of links among routers.
- H : Average distance between routers, in numbers of hops. Note that H includes the distance between a given router and itself, which is equal to zero.
- d : Average size of data packets.
- c : Average size of control packets.
- λ : Communication ratio. This is a number of messages a mobile host receives per second.
- μ : Migration ratio. This is a number of migration per second.

First, we analyze the traffic per migration of one mobile host. The traffic of BN is $2Lc$ since the default router and the previous default router individually broadcast a notification packet to all routers in the same network when a mobile host moves. We assume that BN uses the flooding method as defined in IS-IS protocol to broadcast the notification packets. In the flooding method the control packets are transmitted once on every link. The traffic of BF and that of BQ are 0 since notification packets are not used. In DF and DQ, the traffic costs $2Hc$ because the control packets are exchanged between the current router and the default router for notification and acknowledgment.

We then analyze the traffic per communication. For simplicity, we can omit the traffic between a sending host and its current router and between a receiving host and its current router since the traffic is the same in every strategy. In BN, the data packet can be forwarded along the optimal path, hence the traffic is Hd. The traffic of DF costs $2Hd$, which is as twice as that of BN since the data packet is forwarded to the current router via the default router. In BF, the data packet is forwarded to all routers and then the traffic is NHd. To query the location of the mobile host, BQ

Table 2: Traffic analysis for five strategies.

	BN	BF	BQ	DF	DQ
per communicàtion	Hd	NHd	$(N+1)Hc+Hd$	$2Hd$	$2Hc+Hd$
per migration	$2Lc$	0	0	$2Hc$	$2Hc$
total traffic	$Hd\lambda+2Lc\mu$	$NHd\lambda$	$(N+1)Hc\lambda+Hd\lambda$	$2Hd\lambda+2Hc\mu$	$2Hc\lambda+Hd\lambda+2Hc\mu$

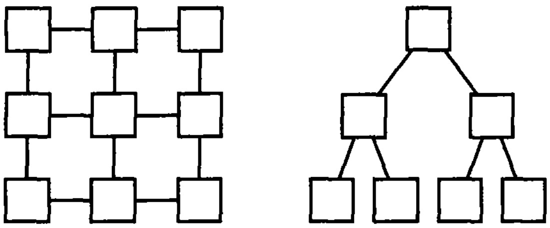

Figure 2: Network topologies: (a) $n \times n$ grid topology ($n=3$); (b) n depth binary tree topology ($n=3$).

and DQ need $(N+1)Hc$ and $2Hc$, respectively. In addition to the control traffic, they need Hd to forward the data packet. We assume that in BF and BQ broadcast is achieved by unicast to all destination.

These analytic results are summarized in Table 2.

3.2 Comparison in Grid Topology

Based on the fundamental analysis discussed above, we then compare the traffic using two examples of network topology. First, we consider an $n \times n$ grid topology as shown in Figure 2 (a). Assume that a mobile host can move to any of the routers.

Here, we have

$$N = n^2,$$
$$L = 2n(n-1),$$
$$H = \frac{2(n-1)(n+1)}{3n}.$$

Let k be μ/λ and l be d/c. We assume $l=1$ for simplicity. The total traffic of each strategy is then given in Table 3. The traffic of DF and that of DQ increase as $O(n)$, while the traffic of BF and that of BQ increase as $O(n^3)$. In other words, DF and DQ have scalability, whereas BF and BQ show the worst performance regarding scalability. On the other hand, since BF and BQ are independent of k, they are efficient for frequent migration.

Figure 3 shows the graphical results. The performance difference among strategies is well represented

Table 3: Traffic comparison in grid topology.

strategy	traffic	
BN	$\frac{2(n-1)(6kn^2+n+1)}{3n}$	$O(n^2)$
BF	$\frac{2n(n-1)(n+1)}{3}$	$O(n^3)$
BQ	$\frac{2(n-1)(n+1)(n^2+2)}{3n}$	$O(n^3)$
DF	$\frac{4(k+1)(n-1)(n+1)}{3n}$	$O(n)$
DQ	$\frac{2(2k+3)(n-1)(n+1)}{3n}$	$O(n)$

in this figure. In addition to the above observation, we can see from this figure that BN is applicable to only such a network in which a host rarely moves.

3.3 Comparison in Binary Tree Topology

Let us consider another example, n depth binary tree topology as shown in Figure 2 (b). Assume that mobile hosts can move to only those routers which are leaves of the topology.

Here, we have

$$N = 2^{n-1},$$
$$L = 2^n - 2,$$
$$H = 2^{2-n} + 2(n-2).$$

We assume $l=1$ to simplify the comparison, and then the total traffic of each strategy is given as shown in Table 4. From this table, we obtain the similar results as in the case of grid topology. That is, DF and DQ are much better than the rest in terms of scalability, while BF and BQ are efficient for frequent migration.

We also show the illustrative results in Figure 4. The same trend as in the gird topology can be seen in this figure. Hence, we can say that the fundamental

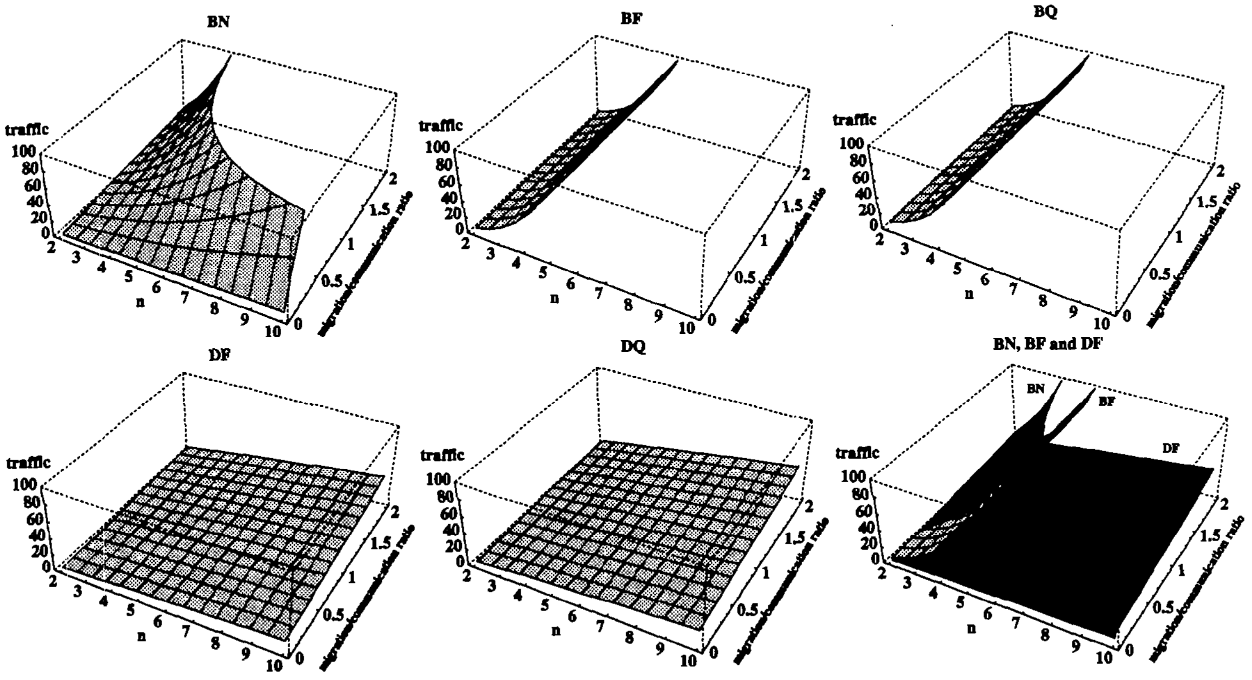

Figure 3: Comparison of total traffic in a grid topology network: n denotes the number of routers on the edge.

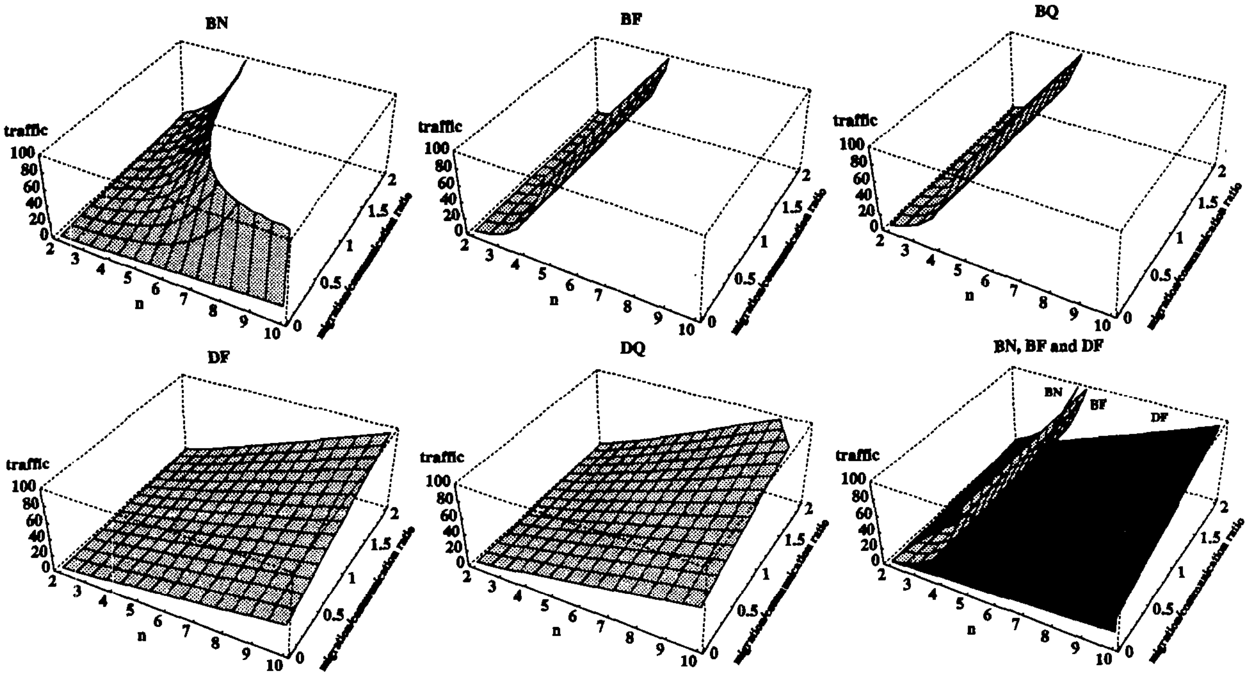

Figure 4: Comparison of total traffic in a binary tree topology network: n denotes the depth of the tree.

Table 4: Traffic comparison in binary tree topology.

strategy	traffic	
BN	$2^{n+1}k - 4(k+1) + 2n + 2^{2-n}$	$O(2^n)$
BF	$2^n(n-2) + 2n$	$O(n * 2^n)$
BQ	$2^n(n-2) + 4n + 2^{3-n} - 6$	$O(n * 2^n)$
DF	$(k+1)(4n + 2^{3-n} - 8)$	$O(n)$
DQ	$(2k+3)(2n + 2^{2-n} - 4)$	$O(n)$

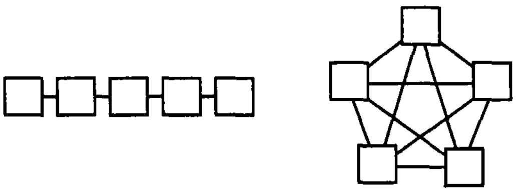

Figure 5: Network topologies representing the cases where H and L are minimum or maximum: (a) linear; (b) complete graph.

characteristics of each strategy are independent of the network topology.

3.4 Comparison in General Topology Network

To ascertain that whether the performance characteristics obtained via previous comparison is true in any network or not, we need further examination. Now we compare five strategies without assumption on network topology and the data/control packet size ratio. For that purpose, we define a new parameter, p, and let p be L/H. Clearly p will change as network topology changes. Using p, we have new formulas for total traffic as shown in Table 5.

From this table, we can see that selection of a strategy depends on the parameters available. BN depends on p, i.e., the network topology, however the others do not. BQ and BF depend on the number of routers, however they are independent of k, i.e., the migration/communication ratio. DF and DQ depend k like BN, though they are independent of p.

In order to grasp the difference among strategies, it will be greatly helpful to show these formulas graphically as a function of k and l at different N. Unlike the graphs shown in Figure 3 and Figure 4, we will show the performance of five strategies in one graph from another point of view. In short, the graph shows the optimal strategy regarding k and l.

The boundary between BN and DF is determined by k which varies according to p, hence we start from examining the range of p. Since p can be calculated for given H and L, we must consider the case where H and L show the smallest/largest value when the given number of routers are equal. Figure 5 depicts such cases: linear topology and complete graph topology.

L is the minimum and H is the maximum in the linear topology, where

$$L = N - 1,$$
$$H = \frac{(N-1)(N+1)}{3N},$$

hence the minimum value of p is $\frac{3N}{N+1}$.

L is the maximum and H is the minimum, on the other hand, in the complete graph topology, where

$$L = \frac{N(N-1)}{2},$$
$$H = \frac{N-1}{N},$$

hence the maximum value of p is $\frac{N^2}{2}$.

As a result, k is minimum in complete graph topology and the value is

$$\frac{2}{N^2 - 2},$$

while k is maximum in linear topology and the value is

$$\frac{N+1}{2N-1}.$$

Figure 6 shows the region of which strategy is optimal regarding given k, l and N in the complete graph topology. Similarly, Figure 7 shows the optimal strategy in the linear topology. Note that the other topologies except the liner topology and the complete graph topology exist between these two extreme cases.

It is easily seen from these figures that the same trend as in the grid topology and the binary tree topology exists in general. That is, BF and BQ are efficient for frequent migration, whereas BN is suitable for the opposite case. DF and DQ have scalability and wide applicability.

Additionally, we can see that DF and DQ gain advantage as the number of links increases as compared with BN. It means DF and DQ can be used in a dense network by which we mean the multi-linked topology network.

Table 5: Traffic comparison considering network topology and data/control packet size ratio.

	BN	BF	BQ	DF	DQ
total traffic $/H\lambda c$	$2pk + l$	Nl	$l + N + 1$	$2k + 2l$	$2k + l + 2$

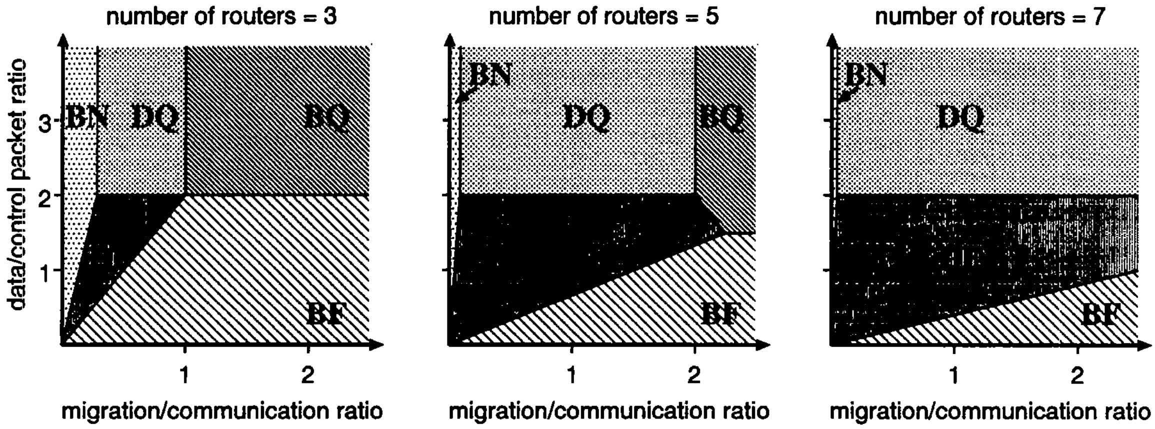

Figure 6: Region of the optimal strategy for given k and l when p is maximum.

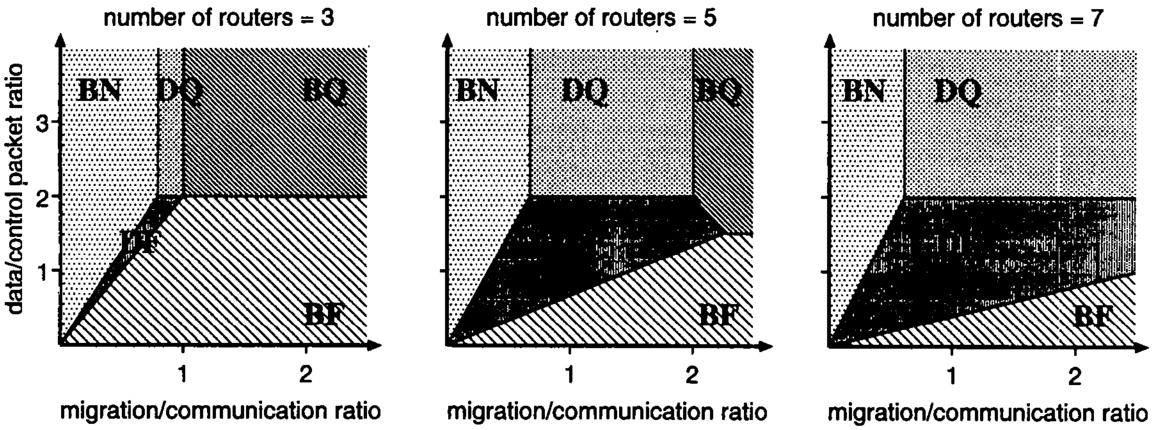

Figure 7: Region of the optimal strategy for given k and l when p is minimum.

4 Conclusion

For each of the mobile support strategies, we have analyzed the traffic per migration and per communication, and thus the total traffic. We have first discussed their performance in two typical network topologies: grid topology and binary tree topology. From these basic comparison, the fundamental characteristics of each strategy have become clear.

BN is useful for small and rare migration network. BF and BQ are suitable if the migration ratio is relatively high in small networks. DF and DQ have advantage of scalability and are applicable for the networks in which the migration ratio is not so high.

In addition, we have discussed the performance difference among the five strategies in general networks. As a result of comparison from wide variety of viewpoint, we have shown that under different network conditions, such as number of routers, network topology, migration/communication ratio, data/control packet size ratio, different strategy produces minimum network traffic.

This result leads us to a new idea that the best performance is obtained if the strategies are changed dynamically according to the network condition. As mentioned in section 2, there are few proposals using two or more strategies, however we should further study about this issue in order to provide mobile users with real performance transparency.

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