RSVMRD: Bandwidth Reservation with Multiple-Route Detection

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For supporting multimedia data transmission with QoS requirement through a computer network, bandwidth reservation is invoked before starting transmission. Here, bandwidth in every communication link on a transmission route from a source computer to a destination one is reserved. Many protocols only reserve bandwidth on an already detected route. Some other protocols combine routing and bandwidth reservation for achieving higher probability of successful reservation. However, it is difficult to complete bandwidth reservation with high traffic in the network. This paper proposes a novel reservation protocol with which multiple transmission routes are used to achieve required bandwidth. Our protocol RSVMRD only searches suitable routes in a bounded part of a network which is achieved by an adhoc routing protocol MRAODV.

複数経路利用によるマルチメディア通信プロトコル

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マルチメディアデータの伝送をコンピュータネットワークを通じて行なう場合、その QoS 要求を満足するために、通信を開始する前に、送信元コンピュータから送信先コンピュータまでの配送経路上にあるルータ間のそれぞれのリンクに対して、帯域幅の予約を行なうことが必要である。RSVP をはじめとするいくつかのプロトコルは、あらかじめ探索、検出された経路に対して帯域幅の予約をする方法がとられている。これに対して、送信元コンピュータから送信先コンピュータまでの複数の経路を探索しながら帯域幅を予約することによって、帯域幅予約の成功確率を高める方法が提案されている。この方法でも 1 つの経路のみを用いてデータの配送を行なうため、単一の経路で要求帯域幅を満足することが求められており、ネットワークのトラフィックが高い状態では予約が成功しない。本論文では、複数の経路を配送に用いる帯域幅予約によって、その成功確率を高める。この予約可能性の判定を行なうために集収するデータを複数経路探索プロトコルによって限定することで、そのオーバーヘッドを削減する RSVMRD プロトコルを提案する。

1 Introduction

Recently, due to highly developed network technology for achieving broadband communication such as ADSL, FTTH, giga-bit ethernet technology, satellite communication and so on, a number of computers connected to the Internet is continuously increased and multimedia messages carrying not only text data but also picture, voice, sound and video data are transmitted. Sometimes these messages are required to be transmitted in realtime manner. In the case of transmission of multimedia messages, since these messages are larger and are required to be transmitted according to QoS requirements such as limitted transmission delay and message loss ratio, bandwidth on communication links along a message transmission route is reserved before starting transmission and is released after finishing it. However, bandwidth of all communication links in the network get not uniquely wider and the network consists of communication links with various remainder bandwidth. On the other hand, required bandwidth by users (network applications) also changes from time to time and topological distribution of bandwidth requirement is also not even. Hence, variance of bandwidth not yet reserved for other communication becomes larger. Since available end-to-end bandwidth from a source computer to a destination one is limitted by the minimum avaliable bandwidth along the transmission route, probability of successful bandwidth reservation gets lower. In order to reserve enough bandwidth for requirement of a network application, communication between computers are realized not by only one message transmission route but by combination of multiple message transmission routes. This paper proposes a novel bandwidth reservation protocol RSVMRD which satisfies required bandwidth by combination of multiple transmission routes. Here, by detection of multiple transmission routes in advance, computational complexity and communication overhead for bandwidth reservation are reduced.

2 Related Works

RSVP (Resource Reservation Protocol) [3] is one of the most widely used protocol for bandwidth reservation in the TCP/IP Internet. In RSVP, a destination computer C_d determines required bandwidth for message transmission from a source computer C_s. First, a bandwidth request message is transmitted from C_d to C_s. Then, on receipt of the bandwidth request message, C_s transmits a bandwidth reservation message along the reversed transmission routes to C_d. Each router on the route reserves required bandwidth for message transmission from C_s to C_d. Since only one message transmission route according to routing tables in intermediate routers configured by a routing protocol is applied, if bandwidth reservation along the route is failed, it is impossible to reserve bandwidth between a source and a destination computers until bandwidth reserved another message transmission is released. On the other hand in protocols proposed in [1, 2, 4–7], route detection and bandwidth reservation are simultaneously achieved. If multiple routes are available from C_s to C_d, probability for satisfying required bandwidth gets higher than the case where only one route is detected. However as discussed in the previous section, since various bandwidth is provided by communication links, required bandwidth changes from time to time and bandwidth requests are unevenly distributed, difference of bandwidth not yet reserved in communication links in the network gets larger. In the consequence, it becomes more difficult for one message transmission route to provide required bandwidth for transmission of multimedia messages that requires larger bandwidth than conventional data messages. However, by using multiple transmission routes simultaneously, it gets possible to achieve required end-to-end bandwidth. For example in Figure 1 (a value included in a pair of parenthesis represents bandwidth not yet reserved for other communication in Mbps unit), for requirement for 8Mbps multimedia message transmission, it is possible to reserve 8Mbps bandwidth in each router along a message transmission route $\langle\langle C_s, R_4, R_5, R_6, C_d\rangle\rangle$.

However in Figure **??**, it is impossible to satisfy requirement for 8Mbps bandwidth reservation from a source computer C_s to a destination one C_d by using only one message transmission route. The available maximum bandwidth through one message transmission route from C_s to C_d is 5Mbps in $\langle\langle C_s, R_4, R_5, R_6, C_d\rangle\rangle$. Hence, communication from C_s to C_d is realized by combination of multiple message transmission routes for achieving required bandwidth. In figure 2, by reserving 5Mbps bandwidth along a route $\langle\langle C_s, R_4, R_5, R_6, C_d\rangle\rangle$ and 3Mbps bandwidth along another route $\langle\langle C_s, R_1, R_2, R_3, C_d\rangle\rangle$, totally 8Mbps end-to-end bandwidth is achieved.

It is difficult to configure multiple routes distributedly for satisfying required bandwidth since remainder bandwidth in a communication link not yet reserved by other communication is kept by a router from which the communication link is issued and it is not possible for a source computer to get the remainder bandwidth in advance. That is, since a source computer does not get bandwidth in all communication links in the network not yet reserved by other communication in advance, by using a distributed reservation method, even though enough bandwidth is not yet reserved, it might be possible to reserve only bandwidth less or to reserve much more bandwidth than required one. On the other hand, if remainder bandwidth of all communication links in the network is kept in a dedicated server computer, each time bandwidth is reserved or released, control messages are required to be exchanged with the server computer. It requires higher communication overhead and the server might become a bottleneck in the network. Hence, on being required to reserve bandwidth for transmission of multimedia messages, remainder bandwidth information in every communication link in the network is gatherred to a source computer. By using the gatherred bandwidth information, a source computer calculates and judges whether it is possible to reserve enough bandwidth on multiple message transmission routes or not by using the labeling scheme. Then, the source computer determines a set of tuples of a communication link for which bandwidth is reserved and bandwidth to be reserved on one of the multiple message transmission routes for satisfying required end-to-end bandwidth.

Now, we show a naive centralized protocol to reserve bandwidth on multiple message transmission routes from a source computer to a destination one by gatherring remainder bandwidth which has not yet reserved by other communication in whole the network (more strictly speaking, in a network consists of all routers that is reachable from a source computer) to a source computer C_s.

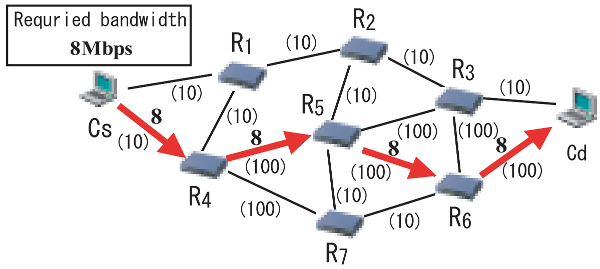

Figure 1: Bandwidth Reservation along One Transmission Route.

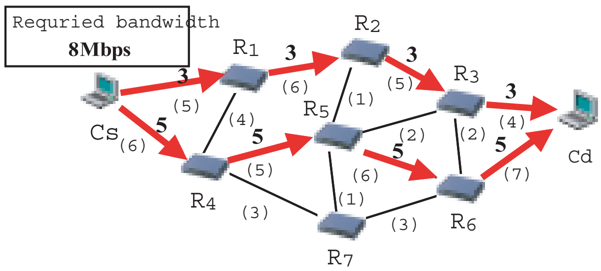

Figure 2: Bandwidth Resenvation along Multiple Transmission.

[Centralized Protocol]

1) A source computer C_s sends bandwidth information request messages to all routers each of which is reachable from C_s by multi-hop message transmission. Here, when a router R_{down} receives the first bandwidth information request message from another router R_{up}, R_{down} registers R_{up} as its upstream router. Then, R_{down} sends copies of the received bandwidth information request message carrying an identifire of R_{up} to all neighbour routers to which R_{down} directly transmits a message. On receipt of the bandwidth information request message, R_{up} registers R_{down} as its downstream router. Hence, a spanning tree whose root is C_s is configured.
2) Every router R_i which is a leaf of the spanning tree, i.e. which has no downstream router, transmits a bandwidth information reply message which carries a set of tuples $[\langle R_i, R_j\rangle, B_{\langle R_i,R_j\rangle}]$ for every communication link $\langle R_i, R_j\rangle$ from R_i to a neighbour router R_j where $B_{\langle R_i,R_j\rangle}$ is bandwidth not yet reserved for other message transmissions to its upstream router.
3) If a router R_i which is on a branch of the spanning tree receives bandwidth information reply messages from all its downstream routers,

R_i transmits another bandwidth information reply message which carries all the tuples carried by the received messages and a set of tuples $[\langle R_i, R_j\rangle, B_{\langle R_i,R_j\rangle}]$ for every communication link $\langle R_i, R_j\rangle$ from R_i to a neighbour router R_j where $B_{\langle R_i,R_j\rangle}$ is bandwidth not yet reserved for other message transmissions to its upstream router.

4) By receiving bandwidth information messages from all downstream routers, C_s achieves information of bandwidth not yet reserved for other communication of all communication links in the network. By applying the labeling scheme based on the information, C_s calculates and achieves reservation request, that is, a set of tuples $[\langle R_i, R_j\rangle, RB_{\langle R_i,R_j\rangle}]$ where $RB_{\langle R_i,R_j\rangle}$ is bandwidth to reserve in a communication link $\langle R_i, R_j\rangle$ are determined. C_s transmits a bandwidth reservation message carrying the set of tuples along to communication links included in the set of tuples. Each router R_i receiving the bandwidth reservation message reserves bandwidth $RB_{\langle R_i,R_j\rangle}$ for a communication link $\langle R_i, R_j\rangle$ issued from R_i and sends a copy of the bandwidth reservation message along $\langle R_i, R_j\rangle$, i.e. to a neighbour router R_j. □

Required computational complexity in the labeling scheme is $O(NL^2)$ where there are N routers and L commuication links in the network. In addition, while C_s gathers remainder bandwidth information and informs reservation request to intermediate routers, all routers in a network should block another request for bandwidth reservation. Hence, higher computational complexity and longer blocking time should be avoided.

3 RSVMRD Protocol

In order to solve the problem discussed in the previous section, this paper proposes a novel bandwidth reservation protocol RSVMRD (ReSerVation with Multiple Route Detection). RSVMRD is designed based on MRAODV (Multiple-Route Ad hoc Ondemand Distance Vector) protocol [8] which is a multiple route detection protocol in a mobile ad hoc network. Here, by applying a procedure of MRAODV protocol, multiple candidates of message transmission routes from a source computer to a destination one are detected distributedly. Then, a source computer gathers information of remainder bandwidth of communication links only included in the above detected message transmission routes and calculates and achieves reservation request in a centralized manner. Thus, RSVMRD is a hybrid reservation protocol of distributed route detection and centralized calculation.

In a computer network composed of a set $R = \{R_1, \ldots, R_m\}$ of routers R_i, a message transmission route $\mathcal{RT}$ from a source computer C_s to a destination one C_d with required bandwidth B_{req}. If a router R_i communicates with another router R_j directly, i.e. without an intermediate router, R_j is a neighbour router of R_i. Every communication link in the network is bi-directional (or symmetric). That is, if message transmission from a router R_i to its neighbour router R_j along a communication link $\langle R_i, R_j\rangle$ is available, opposit message transmission from R_j to R_i along the link is also available. Now, consider a case that $\mathcal{RT}$ consists of only one message transmission route $r^{sd} = \langle\langle C_s = R_0^{sd}, \ldots, R_r^{sd} = C_d\rangle\rangle$. Here, achieved end-to-end bandwidth from C_s to C_d is $B(\mathcal{RT}) = B(r^{sd}) = \min_{i=0,\ldots,r-1} B_{rest}^{\langle R_i,R_{i+1}\rangle}$ where $B_{rest}^{\langle R_i,R_{i+1}\rangle}$ is bandwidth not yet reserved for to other communication in a communication link $\langle R_i, R_i+1\rangle$. As discussed in the previous section, it is possible not to satisfy $R(RT) > B_{req}$.

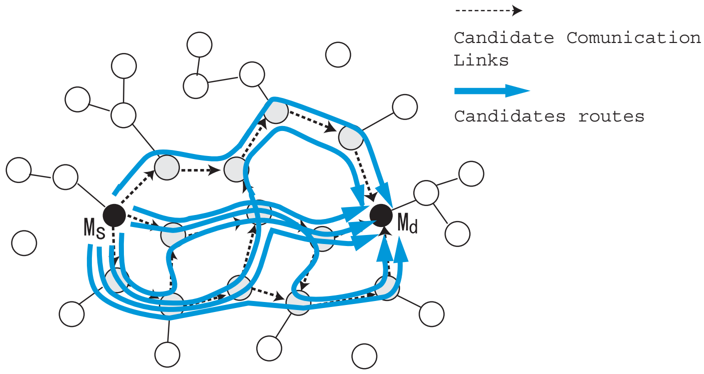

Figure 3: Candidate Transmission routes.

Thus, by configuring $\mathcal{RT}$ with multiple message transmission routes r_i^{sd} $(i = 1, \ldots, N-1)$, achieved end-to-end bandwidth becomes $B(\mathcal{RT}) = B(r^{sd}) = \min_{i=0,\ldots,r-1} B_{rest}^{\langle R_i,R_{i+1}\rangle}$ and probability for satisfying $B(RT) > B_{req}$ gets higher. In this case, in an achieved message transmission route $r^{sd} = \langle\langle C_s = R_0^{sd}, \ldots, R_r^{sd} = C_d\rangle\rangle$, a router R_i never appears at most one time. In addition, if a communication link $\langle R_i, R_{i+1}\rangle$ is included in r^{sd}, a reversed communication link $\langle R_{i+1}, R_i\rangle$ is never included in r^{sd}. Hence, in order for a router R_i to be included in a message transmission route r^{sd}, the following condition should be satisfied:

[Condition]
Let r^{si} and r^{id} be message transmission routes from a source computer C_s to an intermediate router R_i and from R_i to a destination computer C_d, respectively. If R_i is an intermediate router on a message transmission route from C_s to C_d, there is at least one pair of r^{si} and r^{id} where communication links $\forall l \in r^{si}$ and $\forall l' \in r^{id}$ connect same pair of routers and thier directions are different. □

By omitting routers that do not satisfy the above condition and communication links connected to the routers from calculation of the labeling scheme, computational complexity and communication overhead for determining bandwidth reservation request are reduced. This is because such routers are on a sub reverse path that never connected to another sub reverse path and removed in a cut off procedure in MRAODV as shown in Figure 3. In addition in MRAODV, multiple message transmission routes are achieved by connecting neighbouring two branch routes of a spanning tree achieved by a flooding of a control message issued by a source computer. Here, direction of an aditionally used communication link for connecting the neighbouring two branch routes is surely from an upstream router to a downstream one. Hence, detected message transmission routes never contain a communication link directed from a downstream router to an upstream one as shown in Figure 4. Therefore, MRAODV detects shorter message transmission routes and difference of length of detected multiple message transmission routes get smaller. Due to detection of shorter message transmission routes, transmission delay of multimedia message transmission is reduced, i.e. higher realtime property is achieved, and due to achieving smaller difference of length of detected multiple message transmission routes, reduction of jitter and required reception buffer is achieved. If difference of length of detected multiple message transmission routes gets larger, difference of required message transmission delay also gets larger and more receipt buffer for ordering the received messages is required.

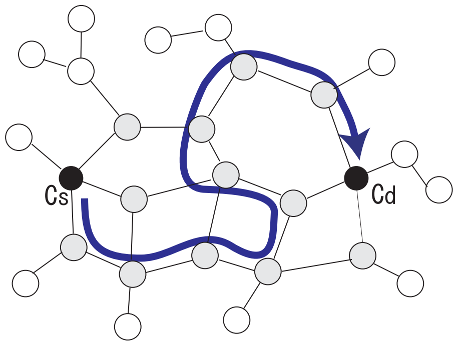

Figure 4: Longer Transmission Route in Centralized Protocol.

[RSVMRD Protocol]

Let FL^{sd} and BL^{sd} be sets of forward and backward links configured in a procedure of MRAODV [8] for detection of multiple message transmission routes from a source computer C_s to a destination one C_d. Here, each router R_i holds a set $BL_i^{sd} \subset BL^{sd}$ of backward links $\langle R_i, R_{up}\rangle$ from R_i to its upstream router R_{up}, a set $FL_i^{sd} \subset FL^{sd}$ of forward links $\langle R_i, R_{down}\rangle$ from R_i to its downstream router R_{down} and bandwidth $B_{rest}^{\langle R_i, R_j\rangle}$ not yet reserved for other message transmissions in a communication link $\langle R_i, R_j\rangle$ issued from R_i to a neighbour router R_j.

(Destination Computer C_d)

1) A destination computer C_d sends bandwidth information aggregation messages to all its upstream routers R_{up} where $\langle C_d, R_{up}\rangle \in BL_d^{sd}$ (and to a source computer C_s if $\langle C_d, C_s\rangle \in BL_d^{sd}$).

(Router R_i)

1) R_i receives a bandwidth information aggregation message from its downstream router R_{down} where $\langle R_i, R_{down}\rangle \in FL_i^{sd}$ (or the destination computer C_d where $\langle R_i, C_d\rangle \in FL_i^{sd}$.)
2) If R_i receives bandwidth information aggregation messages from all its downstream routers, R_i sends copies of another bandwidth information aggregation message which carries all the bandwidth information included in the received bandwidth information aggregation messages and bandwidth information $[\langle R_i, R_{down}\rangle, B_{rest}^{\langle R_i, R_{down}\rangle}]$ for all communication links $\langle R_i, R_{down}\rangle$ to its downstream router R_{down} where $\langle R_i, R_{down}\rangle \in FL_i^{sd}$ (and bandwidth information $[\langle R_i, C_d\rangle, B_{rest}^{\langle R_i, C_D\rangle}]$ for a communication link $\langle R_i, C_d\rangle$ to C_d if $\langle R_i, C_d\rangle \in FL_i^{sd}$) to all its upstream routers R_{up} where $\langle R_i, R_{up}\rangle \in BL_i^{sd}$.

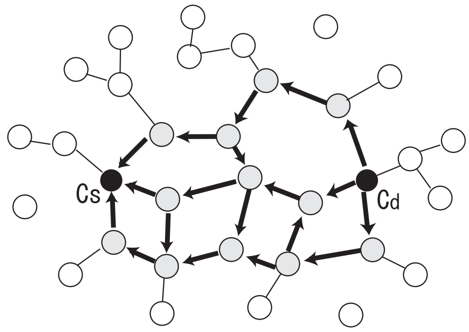

Figure 5: Bandwidth Information Aggregation Messages.

(Source Computer C_s)

1) A source computer C_s receives bandwidth information aggregation messages from its downstream routers R_{down} where $\langle C_s, R_{down}\rangle \in FL_s^{sd}$ (and a destination computer C_d if $\langle C_s, C_d\rangle \in FL_s^{sd}$).
2) If C_s receives bandwidth information aggregation messages from all its downstream routers R_{down} where $\langle C_s, R_{down}\rangle \in FL_s^{sd}$ (and a destination computer C_d if $\langle C_s, C_d\rangle \in FL_s^{sd}$), C_s calculates the maximum bandwidth B_{max} from C_s to C_d by applying the labeling scheme based on bandwidth information $B_{rest}^{\langle R_i, R_j\rangle}$ carried by all the received bandwidth information aggregation messages.
3) If $B_{max} < B_{req}$, even if messages are transmitted through multiple message transmission routes detected by MRAODV protocol, requied bandwidth cannot be achieved. Otherwise, i.e. if $B_{max} \geq B_{req}$, by using a remainder graph in the labeling scheme, a set of reservation requests $[\langle R_i, R_j\rangle, B_{resv}^{<R_i, R_j>}]$ for a communication link $\langle R_i, R_j\rangle$ where $B_{resv}^{\langle R_i, R_j\rangle}$ represents bandwidth to reserve are determined. Then, C_s sends bandwidth reservation messages carrying a set $R_{sv} = \cup_{i,j}[\langle R_i, R_j\rangle, B_{resv}^{\langle R_i, R_j\rangle}]$ of reservation requests to downstream routers where $[\langle C_s, R_{down}\rangle, B_{resv}^{\langle C_s, R_{down}\rangle}] \in R_{sv}$ (and C_d if $[\langle C_s, C_d\rangle, B_{resv}^{\langle C_s, C_d\rangle}] \in R_{sv}$).

(Router R_i)

1) R_i receives a bandwidth reservation message carrying R_{sv} from a router R_{up} where $\langle R_i, R_{up}\rangle \in BL_i^{sd}$ (or a source computer C_s if $\langle R_i, C_s\rangle \in BL_i^{sd}$). If R_i has already received another bandwidth reservation message from $R'_{up} \neq R_{up}$ where $R'_{up} \in BL_i^{sd}$, R_i skips the following steps 2) and 3).
2) R_i reserves bandwidth $B_{resv}^{\langle R_i, R_{down}\rangle}$ in a communication link $\langle R_i, R_{down}\rangle$ where

$[\langle R_i, R_{down}\rangle, B_{resv}^{\langle R_i, R_{down}\rangle}] \in R_{sv}$. In addition, R_i updates $B^{\langle R_i, R_{down}\rangle} \leftarrow B^{\langle R_i, R_{down}\rangle} - B_{resv}^{\langle R_i, R_{down}\rangle}$.

3) R_i sends copies of the received bandwidth reservation message to its downstream router R_{down} where $[\langle R_i, R_{down}\rangle, B_{resv}^{\langle R_i, R_{down}\rangle}] \in R_{sv}$ (or C_d if $[\langle R_i, C_d\rangle, B_{resv}^{\langle R_i, C_d\rangle}] \in R_{sv}$).

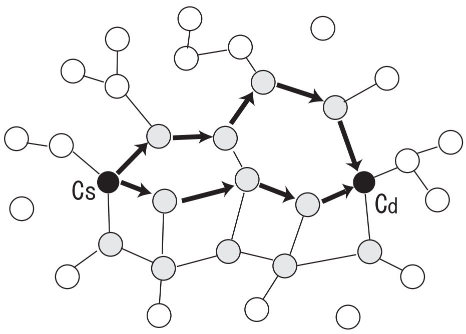

Figure 6: Bandwidth Reservation Messages.

(Destination Computer C_d)

1) C_d receives bandwidth reservation messages from its upstream mobile computers R_{up} where $[\langle R_{up}, C_d\rangle, B_{resv}^{\langle R_{up}, C_d\rangle}] \in R_{sv}$. □

4 Evaluation

In this section, we show some simulation results in order to evaluate performance of the proposed protocol RSVMRD compared with the centralized protocol discussed in Section 2. Here, we evaluate numbers of required control messages for reservation of bandwidth and required time duration since initiation of RSVMRD protocol until start of transmission of application messages.

Table 1 shows comparison results of computational complexity, numbers of control messages and required time duration for reservation. Here, N is a number of routers in a network reachable from a source computer by multi-hop message transmission, total number of uni-directional communication links in the network of the N reachable routers is $2L$ (a bi-directional link between two neighbour routers is counted as 2 in this case) and the maximum hop count in the N reachable routers is D. In addition, n is a number of routers included in at least one of the message transmission routes from a source computer C_s to a destinaStion one C_d detected by MRAODV protocol, total number of uni-directional communication links in at least one of the detected routes is l and the maximum hop count from C_s to C_d along one of the detected transmission routes is d. Finally, n' is a number of routers included in at least one of message transmission routes on which bandwidth is reserved, total number of uni-directional communication links on which bandwidth is reserved is l' and the maximum hop count from C_s to C_d along one of the message transmission routes on which bandwidth is reserved is d'. Due to usage of the labeling scheme, computational complexity in RSVMRD is $\alpha nl^2 + \beta$ and one in the centralized protocol is $4\alpha nL^2 + \beta$. In RSVMRD, $2L + 2n$ control messages are transmitted for MRAODV protocol and l bandwidth information aggregation messages and l' bandwidth reservation messages are transmitted. Hence, totally, $2L + 2n + l + l'$ control messages are exchanged in RSVMRD. On the other hand, in the centralized protocol, $2L$ bandwidth information request messages are transmitted in flooding issued by a source computer, N bandwidth information reply messages are transmitted to gather remainder bandwidth information to C_s and l' bandwidth reservation messages are transmitted to reserve bandwidth. Hence, totally, $2L + N + l'$ control messages are exchanged in the centralized protocol. Finally, $D + d$, d and d' are required for MRAODV, transmission of bandwidth information aggregation message and transmission of bandwidth reservation message, respectively. Hence, $D + 2d + d'$ time duration is required in RSVMRD. On the other hand, $2D$ and d' are required for the centralized protocol to transmit bandwidth information request messages and bandwidth information reply messages, respectively. Hence, totally, $2D + d'$ time duration is required in the centralized protocol. In all the three evaluation items, the value depends on a network topology. However, since $N \geq n$ and $L \geq l$ are surely satisfied, RSVMRD achieves lower computational complexity than the centralized protocol.

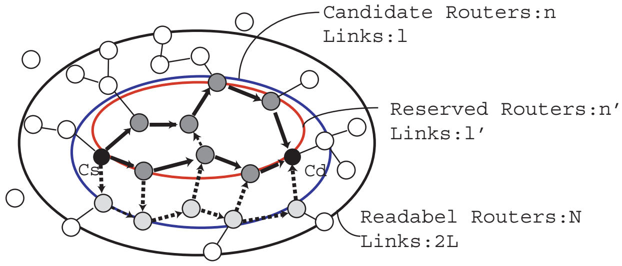

Figure 7: Evaluation Parameters.

Table 1: Evaluation Results.

	RSVMRD	Centralized
computational	$\alpha nl^2 + \beta$	$4\alpha NL^2 + \beta$
messages	$2L + 2n + l + l'$	$2L + N + l'$
time	$D + 2d + d'$	$2D + d'$

Next, we evaluate performance of these protocols in simulation. Here, a number of routers in the network and an average number of neighbour routers which represents network connectivity are changed. Figures 8,9,10 and 11 show conputational complexity, numbers of transmitted control messages, avarage and variance of hop counts of detected transmission routes. Avaragely, RSVMRD achieves higher performance in every criteria, that is, 1/40 computational complexity is required, 14.1% control messages are reduced, 20.4% shorter transmission routes are detected and 70.5% smaller variance of transmission route length is achieved.

5 Conclusion

This paper proposes a novel bandwidth reservation protocol RSVMRD where required bandwidth is achieved with higher probability by using multiple transmission routes from a source computer to a destination one and shows simulation results for comparing performance with a conventional centralized protocol.

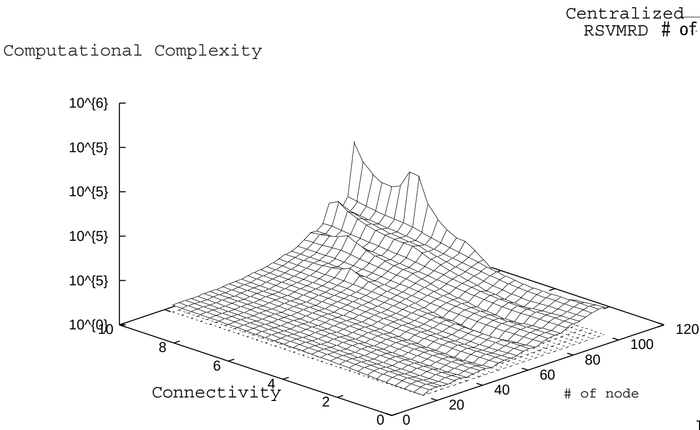

Figure 8: Computational Complexity.

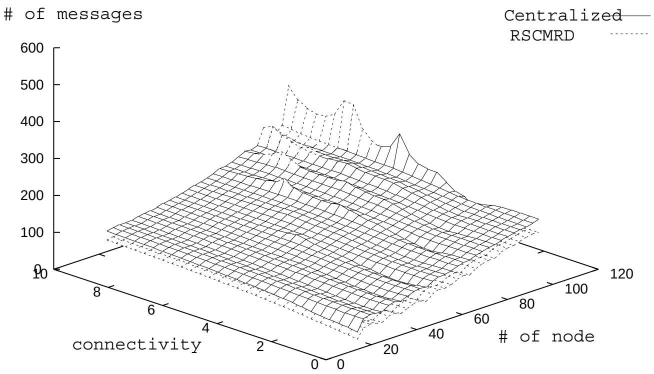

Figure 9: Numbers of control Messages.

References

[1] "ATM Forum Technical Committee. Private Network-Network Interface(PNNI)v1.0," Specification af-pnni-0055.000, (1996).

[2] Shin, K.G. and Chou, C.C, "A Distributed QoS Routing Using Bounded Flooding," University of Michigan CSE technical report, CSE-TR-388-99. (1999).

[3] Braden, R., Zhang, L., Berson, S., Herzog S. and jamin S., "Resource ReSerVation Protocol(RSVP) – Version 1 Functional Specification," IETF RFC 2205 (1997).

[4] Cidon, I., Rom, R. and Shavitt, Y., "Multi-path routing combined with resource reservation," INFOCOM '97. Sixteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings IEEE, Vol 1, pp. 92–100 (1997).

[5] Pung, H.K., Song, J. and Jacob, L., "Fast and efficient flooding based QoS routing algorithm," Computer Communications and Networks, 1999. Proceedings. Eight International Conference, pp. 298–303 (1999).

[6] Xin. Y., Hui. D., Yuan. Z. and Jie. Z., "Resource reservation mechanisms for distributed multi-path quality of service routing," Computer Communications and Networks, 2000. Proceedings. Ninth International Conference, pp. 9–13 (2000).

[7] Yuan, Z. and Xin, Y., "Impact of resource reservation on the distributed multi-path quality of service routing scheme," Quality of Service, 2000. IWQOS. 2000 Eighth International Workshop, pp. 95–104 (2000).

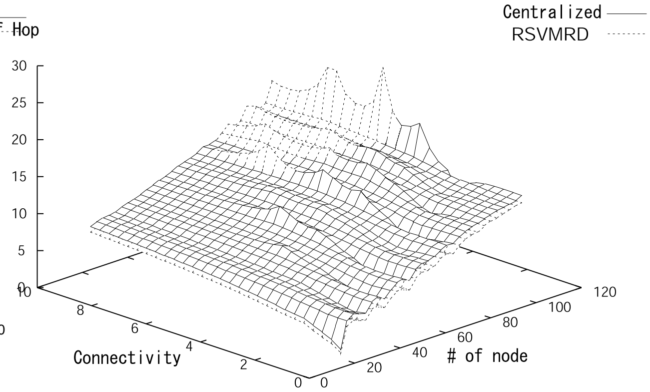

Figure 10: Hop Counts along Detected Routers.

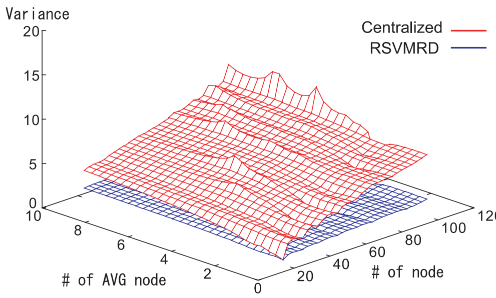

Figure 11: Vaviance of Hop Counts.

[8] Higaki, H. and Umeshima, S., "Multiple-Route Ad-Hoc Ondemand (MRAODV) Routing Protocol," Proceedings of the 18th International Parallel and Distributed Processing Symposium, CD-ROM (2004).