계층적 이동 IPv4 환경에서 VPN 운영 방안

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요 약

본 논문은 외부 에이전트의 계층적인 구조를 이용하여 VPN과 이동 IPv4의 효과적인 연동 방안을 제시한다. 제안된 방안에서, 대표 외부 에이전트(Gateway Foreign Agent)는 이동 노드를 대신하여 VPN 게이트웨이 역할을 수행한다. 이동 노드가 같은 GFA 영역 내에서 이동 시, GFA가 이동 노드 대신 홈 네트워크에 위치한 VPN 게이트웨이와의 IPsec 보안 협정을 이미 가지고 있기 때문에, 이동 노드는 새로운 IPsec 협정을 맺을 필요 없이 데이터를 전송하면 된다. 이러한 방법으로, 본 논문은 IPsec 재협정으로 인한 메시지 오버헤드와 지연을 감소시키며, 이동 노드가 외부 망에 있을 경우 패킷 누출 없이 안전하게 데이터를 전송할 수 있다. 수학적 분석 모델을 이용하여 제안된 방안의 성능을 증명하며, 분석 결과는 제안된 방식이 기존의 연동방식 보다 등록 갱신 비용과 패킷 전송 비용 측면에서 우수하다는 것을 보여준다.

VPN Traversal Scheme in Hierarchical MIPv4 environment

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ABSTRACT

This paper presents an efficient interoperation scheme of a VPN(Virtual Private Network) and Mobile IP using a hierarchical structure of a FA(Foreign Agent). In the proposed scheme, the GFA(Gateway Foreign Agent) plays a role of VPN gateway on behalf of the MN(Mobile Node). When the MN moves in the same GFA domain, because the GFA has already an IPsec security association with a VPN gateway in the home network of the MN, the MN does not need an IPsec re-negotiaion. In this way, our mechanism reduces a message overhead and a delay resulted from an IPsec negotiation. And a MN can send a data to a correspondent node without a packet leakage. We show a performance of our scheme by using a discrete analytical model. Analytical results demonstrated that the total processing cost calculated by a registration update cost and a packet delivery cost is significantly reduced through our proposed scheme.

키워드 : 이동 IP(Mobile IP), VPN, IPsec

1. Introduction

Mobile IP agents are being deployed in enterprise networks to enable a mobility across wired and wireless. With the growing deployment of IEEE 802.11 access points in public places such as hotels, airports, and convention centers, the need for enabling MNs(MNs) to maintain their transport connections and constant reachability while the MN is connecting back to their home network protected by Virtual Private Network(VPN) technology is increasing. This implies that MIP and VPN technologies have to coexist and function together in order to provide mobility and security to the MNs. The VPN requires that a new IKE negotiation be done whenever an IPsec peer moves because it is based on the IPsec. In other words, whenever the MN moves to the other network, it requires a new IPsec association. In this environment, the MN experiences a severe delay and overhead resulted from IPsec re-association. There are few studies to solve these problems. Reference [4] identifies and describes practical deployment scenarios for MIP and VPN using an X-HA. But the induction of X-HA is impossible to realize and the MN has a large overhead. Reference [2] suggests a basic solution about an applicability statement of a MIPv4 and IPsec to provide the session mobility between aninternal and external network.

This paper proposes the efficient interoperation scheme of VPN and MIP using a hierarchical FA structure. Because the GFA plays a role of VPN gateway on behalf of the MN in the proposed scheme, the MN does not need an IKE negotiation whenever a MN moves to the other network. When the mobile node moves in the same GFA, it doesn't

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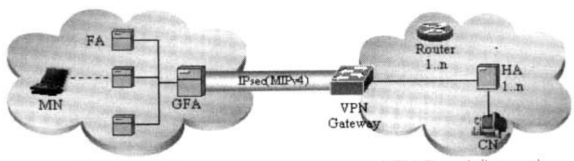
need a new IKE negotiation because the GFA has already had an IPsec SA with a VPN gateway in the MN's home network. In this way, our mechanism can reduce a message overhead and delay resulted from an IKE re-negotiation.

The rest of the paper is organized as follows. Section 2 presents the general topology of operation. Section 3 introduces a new mechanism to provide a VPN interoperation in the hierarchical MIP environment. Section 4 evaluates the performance and compares the proposed method with the existing protocols. Finally, we conclude this paper in Section 5.

2. Topology

The network topology is illustrated in (Figure 1). The home network is typically a multi-subnetted network which uses private addressing. Subnets may contain home agent(HA)s, VPN Gateway, etc.



(Figure 1) Network Topology

FAs are organized hierarchically. At the top level of the hierarchy, there is at least one Gateway Foreign Agent (GFA), a FA with additional functions. There are one or more regional FAs beneath one GFA. We assume that these FAs are trusted parties.

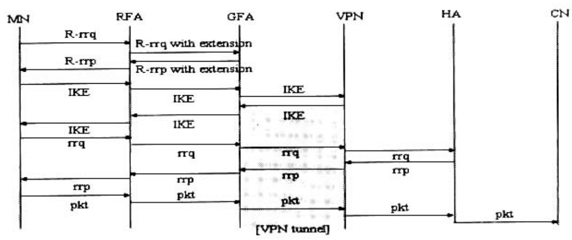
3. Protocol overview

The mobile node(MN) is located inside ofa VPN domain before a movement. We suppose that a correspondent node locates in a MN's home network. When a MN arrives at a visited domain, it should create an IPsec tunnel with a VPN gateway in the home network to send a data to a correspondent node. Because an IPsec, as currently specified [3] requires that a new IKE negotiation be done whenever an IPsec peers moves, the MN experiences a message overhead and delay resulted from the IKE re-negotiation.

In our mechanism, the GFA plays a role of a VPN gateway. If the MN does not have an existing IPsec SA with the VPN gateway, it creates an IPsec SA using the address of GFA for an IKE/IPsec communication. When the MN moves in the same GFA, the MN doesn't need a new IKE negotiation because the GFA has already had an IPsec SA with a VPN gateway in the MN's home network.

3.1 Registration at the GFA

The (Figure 2) shows a registration procedure at the MN's GFA. When a MN first arrives at a visited domain, it performs a registration with its home network. We assume that all domains support a regional registration. Therefore, the HA registers an address of GFA at this registrationprocedure. But, this registration message should be sent inside the IPsec tunnel. When the MN moves to a new GFA region, if it isn't registered at the GFA, it cannot create an IPsec SA using an address of GFA. Therefore, we suggest new messages, which are the R-rrq message and the R-rrp message with an extension field. These two messages are used for the MN to register locally at the GFA. After registering at the GFA, the MN begins an IKE negotiation with VPN gateway.



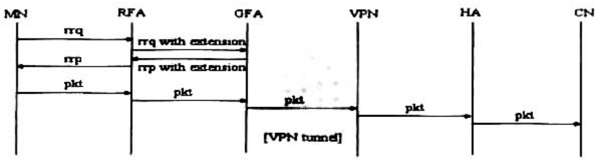
(Figure 2) Registration at the GFA

At this time, the source address of an inner tunneling of IKE negotiation packet is the GFA's address and the destination address of inner tunneling is the VPN gateway's address. After an IKE negotiation, the MN sends a registration request message to the HA through the IPsec tunnel. After a registration, the MN sends a data packet to a correspondent node through an IPsec tunnel. In this way, the MN creates a new IKE negotiation only when it moves to the new GFA region.

3.2 Regional registration at the GFA

When the MN moves in the same GFA, it registers at RFA in a general registration way. Because the GFA maintains an IPsec tunnel with a VPN gateway of MN's home domain, the MN does not need an IKE negotiation procedure. After the regional registration, the MN can send a packet to a correspondent node using an existing VPN tunnel. The procedure of the regional registration is illustrated in

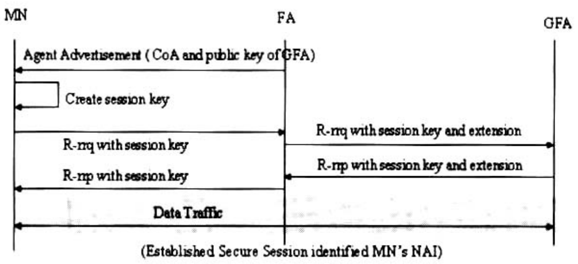
(Figure 3).



(Figure 3) Regional Registration at the GFA

3.3 Security consideration

In this section, we consider a MN which doesnot support an IPsec. In such an environment, we divide a security domain into two parts. One part is a domain between a GFA and VPN gateway. This security domain uses an IPsec-based VPN tunnel. To send packets to HA, the GFA re-generates all packets which are received from MN or VPN gateway. The other part is a domain between the MN and GFA. This domain does not apply IKE to establish SA because MN's care-of address can frequently change. Therefore, we need to use our proposed method for a key exchange between the MN and GFA.



(Figure 4) Tunnel Establishment between the MN and the GFA

The (Figure 4) describes a procedure to establish a security tunnel between a mobile node and GFA. We assume that GFA has an asymmetric key for a key exchange and both GFA and MN have an encryption function of an IP layer level.

First, the MN can get the care-of address of the FA and GFA, and a public key of the GFA by an agent advertisement message. The MN creates a session key and encrypts the key by a public key of GFA and the MN sends it to a GFA. The session key is a NAI of MN. All packets are encrypted using a session key. In this way, the secure session between the MN and GFA is created. When the MN moves one FA to another FA inside of the same visited domain, the previous secure session is still useful because it is identified not by the care-of address of the MN but by the NAI of the MN.

4. Performance Analysis

In this section, we derive the cost function of registration update and packet overhead of our scheme and the one of the existing scheme. The total processing cost in a registration update and packet delivery is considered as the performance metric. We do not take the periodic binding updates that a MN sends to it's HA or FA to refresh their cache into account.

4.1 Registration update cost

This registration update cost includes a cost to create an IPsec tunnel between the MN and VPN gateway or between the GFA and VPN gateway. We define the following parameters for registration update in the rest of this paper:

- a_h : The registration update processing cost at the HA
- a_g : The registration update processing cost at the GFA
- a_f : The registration update processing cost at the RFA
- a_v : The registration update processing cost at the VPN gateway
- C_{hv} : The transmission cost of registration update-between the HA and VPN gateway
- C_{gf} : The transmission cost of registration update between the GFA and RFA
- C_{vg} : The transmission cost registration update between the VPN gateway and GFA
- C_{gh} : The transmission cost of registration update between the GFA and HA
- C_{ike} : The IKE negotiation cost between the GFA and VPN gateway, between the MN and VPN gateway

The home registration cost and the regional registration cost can be calculated as :

$$C_{Uh} = 2a_f + 2a_g + a_h + 2a_v + 2(C_{hv} + C_{gf} + C_{vg} + C_{fm} + C_{gh}) \quad (1)$$

$$C_{Ur} = 2a_f + a_g + 2(C_{gf} + C_{fm}) \quad (2)$$

Let l_{hv} be the average distance between the HA and the VPN in terms of the number of hops, l_{gf} be the average distance between the GFA and the RFA, l_{vh} be the average distance between the VPN gateway and the HA. We assume the transmission cost is proportional to the distance and the proportionality constant is δ_U. *Thus* C_{hv}, C_{gf}, C_{vg}, C_{gh} can be expressed *as* $l_{vh}\delta_U$, $l_{gf}\delta_U$, $l_{vg}\delta_U$ and $l_{gh}\delta_U$. Since usually the transmission cost of the wireless link is generally higher than that of the wired link, we suppose that the transmission cost over the wireless link is ρ times higher than the unit distance wireline transmission cost. Then the home registration and regional registration costs can be expressed as :

$$C_{Uh} = 2a_f + 2a_g + a_h + 2a_v + 2(l_{hv} + l_{gf} + l_{vg} + \rho + l_{gh})\,\delta_U \quad (3)$$

$$C_{Ur} = 2a_f + a_g + 2(l_{gf} + \rho)\,\delta_U \quad (4)$$

The γ is a constant for an IKE negotiation. The IKE negotiation cost of MN and VPN gateway is $C_{ike} = \tau l_{mv}$ and the one of VPN gateway and GFA is $C_{ike} = \tau l_{vg}$.

Assume each MN may move randomly among N subnets and there are k subnets in a regional network. We model the movements of a MN as a discrete system. Define a random variable M so that each MN moves out of a regional network at move M. At movement 1, a MN may moves to either subnet 1, 2, ⋯ or N. At movement 2, the MN may move to any of the other N-1 subnets. We assume that the MN will move out to the other N-1 subnets with equal probability, $\frac{1}{N-1}$. In the regional registration, the probability of moving out of a regional network, the probability of performing a home registration at movement m is :

$$P^m = \frac{N-k}{N-1} \cdot \left(\frac{k-1}{N-1}\right)^{m-2}, \text{ where } 2 \le m < \infty \quad (6)$$

The expectation of M is like followings :

$$E[M] = \sum_{m=2}^{\infty} mP^m = 1 + \frac{N-1}{N-k} \quad (7)$$

Assume that the average sojourn time in each subnet within a regional network is T_f. In our mechanism, the IKE negotiation procedure happens only once when the MN moves to the new GFA region. Therefore, the average registration cost for regional registration is (includes an IKE negotiation time) :

$$C_{Ours-RU} = \frac{(E[M]+1)C_{Ur} + C\,Uh + \tau h_{vg}}{E[M]T_f} \quad (8)$$

When our mechanism is not used, the IKE negotiation procedure happens whenever the MN moves to the new subnet. Therefore, the average registration cost is :

$$C_{notrr-RU} = \frac{(E[M]+1)(C_{Uh} + \tau h_{mv})}{E[M]T_f} \quad (9)$$

4.2 Packet delivery cost

The packet delivery cost includes the transmission and processing cost to route a tunneled packet from the HA to the VPN gateway, from the VPN gateway to the GFA, from the GFA to the RFA. We define the following parameters for a packet delivery cost in the rest of this paper :

- U_h : The packet delivery processing cost at the HA
- U_g : The packet delivery processing cost at the GFA
- U_f : The packet delivery processing cost at the RFA
- U_v : The packet delivery processing cost at the VPN gateway
- T_{hv} : The transmission cost of packet deliverybetween the HA and VPN gateway
- T_{gf} : The transmission cost of packet delivery between the GFA and RFA
- T_{vg} : The transmission cost of packet delivery between the VPN gateway and GFA
- T_{gh} : The transmission cost of packet delivery between the GFA and HA

The cost for packet delivery procedure can be expressed as :

$$C_{ours-PD} = U_h + U_g + U_f + U_v + T_{hv} + T_{gf} + T_{vg} + T_{gh} \quad (10)$$

We assume the transmission cost of delivering data packets is proportional to the distance between the sending and the receiving mobility agentwith the proportionality constant δ_D. Then T_{hv}, T_{gf}, T_{vg}, T_{gh} can be expressed as $l_{vh}\delta_D$, $l_{gf}\delta_D$, $l_{vg}\delta_D$, $l_{fm}\delta_D$ and $l_{gh}\delta D$. Assume on average there are ω MNs in a subnet. GFA serves all MNs which move inside of a regional network, and the total number of MNs in a regional network is ωk on average. Therefore, the complexity of the GFA visitor list lookup is proportional to ωk.

We define the packet deliverycost functions at the GFA as :

$$U_g = \varsigma k \cdot \lambda_a(\alpha\omega k + \beta\log(k)) \quad (11)$$

where λ_a is the packet arrival rate for each MN, α and β are weighting factor of visitor list and routing table lookups and ζ is a constant which captures the bandwidth allocation cost at the GFA. The processing cost function at the HA can be defined as : $U_h = \eta\lambda_a$, where η is a packet delivery processing cost constant at the HA. The processing cost function at the VPN gateway can be defined as : $U_v = \xi\lambda_a$ where ξ is a packet delivery processing cost constant at the VPN gateway. Then the total packet delivery cost per unit time for our scheme is :

$$C_{ours-PD} = \varsigma\lambda_a(a\omega k+\beta\log(k)) + (l_{vh}+l_{vg}+l_{gh}+l_{gf}+\rho)\delta_D + (\eta+\xi)\lambda_a \quad (12)$$

When the regional registration is not used, the packet processing cost functions at the FA is same with the cost of above GFA. Therefore, the total packet delivery cost per unit time for the existing scheme is :

$$C_{Notrr-PD} = \varsigma\lambda_a(a\omega k+\beta\log(k)) + (l_{vh}+l_{vf}+\rho)\delta_D + (\eta+\xi)\lambda_a \quad (13)$$

4.3 Total processing cost

The total processing cost is calculated by a sum of the registration update cost and the packet delivery cost. Based on the above analysis, we may get the total processing cost function as :

$$C_{(\cdot)-TOT}(k,\lambda_a,T_f) = C_{(\cdot)-RU} + C_{(\cdot)-PD} \quad (14)$$

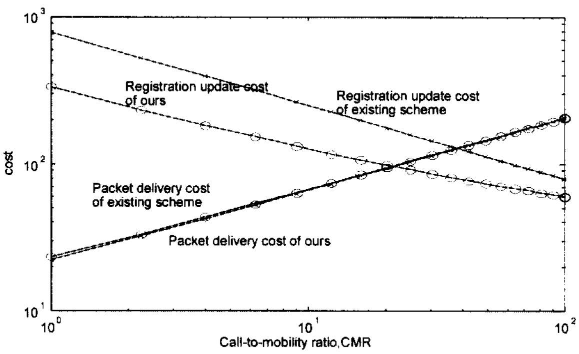
5. Analytical Results

In this section, we demonstrate the performance improvement of our scheme over the existing scheme, using an above a total signaling cost. Also, we simulated the proposed mechanism using a NS-2 to verify an output value resulted from an above numerical analysis. Since the total number of subnets that MNs access through wireless channels is limited, we assume w = 30. For our evaluation, l_{vh}, l_{gf}, l_{vg} and l_{gh} is fixed numbers. If not, signaling packets may take different paths each time according to the traffic load and routing algorithms at each mobility agent. Thus, l_{vh}, l_{gf}, l_{vg} and l_{gh} vary within a certain range. An MN may use the TTL field in packet headers to get the number of hops packets travel. Since the TTL field in IP header is usually initialized to 32 or 64, the upper limit on the number of hops through which a packet can pass is 32 or 64, we assume l_{vh} = 5, l_{gf} = 10, l_{vg} = 15 and l_{gh} = 20. The home agent has the highest packet processing cost since the home agent maintains the visitor list whenever the registration packet arrives at. Since we suppose that the private network has the smaller size than the public network, the l_{gh} value is smaller than the other length constant The bandwidth allocation cost at GFA is usually far lower than the packet delivery cost Therefore, we consider the packet delivery cost at VPN, HA, as 10 and the bandwidth allocation cost at GFA as 0.001. <Table 1> lists some of the parameters used in our performance analysis. In the simulation, we used same parameters in <Table 1>.

〈Table 1〉 Parameters for performance analysis

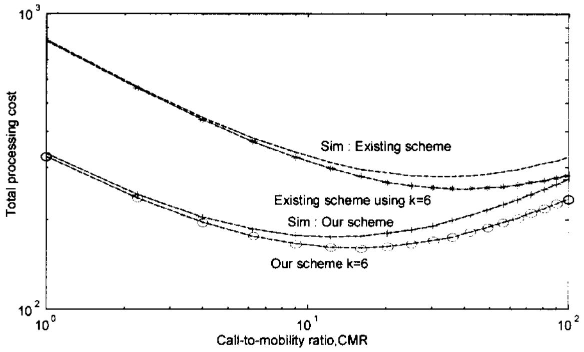
Pkt process cost	a_h	25.0	Pkt processing constant	η	10
	a_g	15.0		ζ	0.001
	a_f	10.0		ξ	10
	a_v	17.0		ς	5
Distance Cost Unit	δ_U	0.1	Weight	α	0.3
	δ_D	0.05		β	0.7
IKE factor	τ	12.0	Number of MNw	w	15
			Wireless Factor	ρ	10

First, we compare our scheme with the existing scheme by using the call-to-mobility (CMR). We define the call-to-mobility as the ratio of the packet arrival rate to the mobility rate, CMR= $\lambda_a T_f$. We assume that the average values of residence time in each subnet and packet arrival rate of all the MNs are the same. When the CMR is low, the mobility rate is higher than a packet arrival rate. In other words, the registration update cost dominates a total signaling cost. (Figure 5) shows the comparison result of registration update cost and packet delivery cost as a function of CMR for the two schemes. Our scheme has a better performance result in the aspect of registration update cost since the registration update cost includes an IKE negotiation cost and our scheme has a hierarchical structure.



(Figure 5) Comparison of registration update cost and packet delivery cost based on the CMR

(Figure 6) shows the total processing cost as a function of CMR for the two schemes when the arrival rate and residence time increase at the same time. When the CMR value is low, because the higher mobility rate results many registrations and IPsec negotiations in existing scheme, our scheme performs far better than the existing scheme. In the experiment, the network size of two schemes is k=6. In (Figure 6), the two red lines show simulation results. In the simulation, our scheme can save a total processing cost to 22% compared to the existing scheme and we could show the similar result to a numerical analysis.

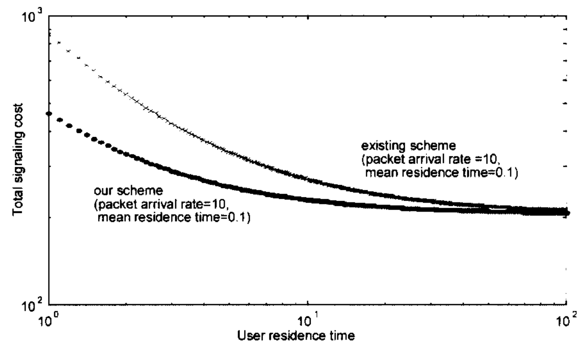


(Figure 6) Comparison of total signaling cost based on the CMR

In the second experiment, we assume that the residence time of users follows an exponential distribution, like :

$$f_1(T_f) = \frac{1}{\overline{T}_{f1}} e^{-T_f/\overline{T}_{f1}}, \quad T_f \geq 0 \tag{15}$$

Let the packet arrival rate λ_a be the fixed number, λ_a=10 and the average residence time $\overline{T}_{f1}$=0.1. (Figure 7) shows the comparison of total processing cost under an exponential distribution of user movement pattern.



(Figure 7) Comparison of total signaling cost under user with an exponential distribution

Therefore, the total processing cost of our scheme and existing scheme are :

$$C_{TOT} = \int_0^\infty f_1(T_f)\, C_{(\cdot)-TOT}(k=6, \lambda_a, T_f))\, dT_f \tag{16}$$

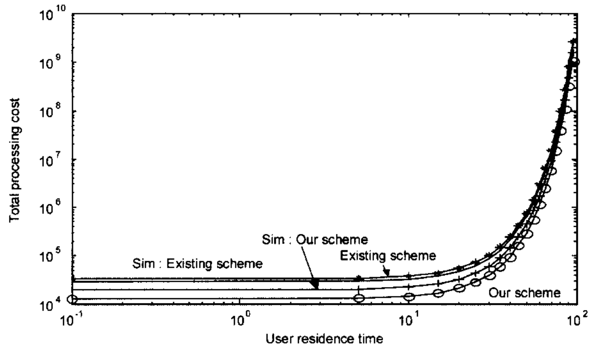
Although the performance improvement of our scheme is not large under the user residence time of above 10^2, our scheme shows a high performance in the most user residence time.

At this time, we assume that the residence time of user follows a Gaussian distribution :

$$f_2(T_f) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(T_f - \overline{T}_{f2})^2/2\sigma^2}, \quad T_f \geq 0 \tag{17}$$

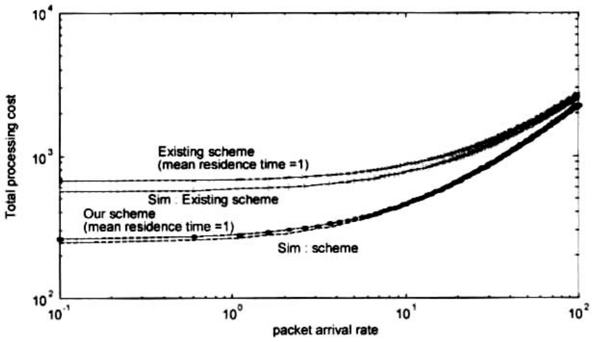
$$C_{TOT} = \int_0^\infty f_1(T_f)\, C_{(\cdot)-TOT}(k=6, \lambda_a, T_f))\, dT_f \tag{18}$$

Let the packet arrival rate be the constant and the average residence time $\overline{T}_{f1}$ = 0.1. (Figure 8) shows the comparison of total processing cost under a Gaussian distribution of user movement pattern. Because the long residence time makes an IKE negotiation not happen frequently, the total processing cost of our scheme is lower than the existing scheme to the some extent. In (Figure 8), the two red lines show simulation results. In the simulation, our scheme cannot save the processing cost compared to the existing scheme under the long residence time.



(Figure 8) Comparison of total processing cost under user with a Gaussian distribution

We assume that the residence time of users is fixed number, T_f =1 and the arrival rate changes. (Figure 9) shows the total processing cost of our scheme and existing scheme as a function of a packet arrival rate under a mean residence time=1. When the packet arrival rate is high, the processing cost of our scheme is almost as same as one of it. But, when the packet arrival rate is low, we can save a total processing cost to the about 20%. This is resulted from what the packet processing cost excesses a registration update cost. In (Figure 9), the two red lines show simulation results. In the simulation, the higher packet arrival rate, we can save the less processing cost to be compared with the existing scheme and our numerical analysis result is verified.



(Figure 9) Comparison of total signaling cost under packet arrival rate

6. Conclusion

In this paper, we introduced the efficient interoperation scheme of VPN and Mobile IP using a hierarchical structure of FA. Since the GFA plays a role of VPN gateway on behalf of the MN in the proposed scheme, the MN does not need an IKE negotiation whenever a MN moves to the other network. When the mobile node moves inside of the same GFA, the mobile node doesn't need a new IKE negotiation because the GFA has already had an IPsec SA with a VPN gateway in the home network of the MN. In this way, our mechanism can reduce a message overhead and delay resulted from an IKE re-negotiation efficiently. By using a discrete analytical model for cost analysis, we compare the proposed scheme with an existing scheme under the total signaling cost. Analytical results demonstrated that the total processing cost was significantly reduced through our proposed scheme

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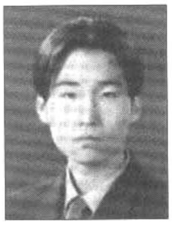

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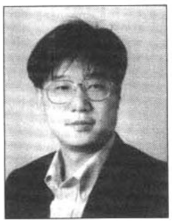
관심분야 : 이동컴퓨팅, QoS, DRM, 오버레이 멀티캐스트 등



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