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Implementation and Experimental Evaluation of TeleMIP

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Implementation and Performance Evaluation of TeleMIP *

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Abstract—

In this paper, we present our implementation of TeleMIP, a two-level architecture for IP-based mobility management. TeleMIP essentially uses an Intra-Domain Mobility Management Protocol (IDMP) for managing mobility within a domain, and Mobile IP for supporting inter-domain (global) mobility. Unlike other proposed schemes for intra-domain mobility management, IDMP uses two care-of addresses for mobility management. The global care-of address is relatively stable and identifies the mobile node's current domain, while the local care-of address changes every time the mobile changes subnets and identifies the mobile's current point of attachment. The paper describes our TeleMIP implementation based on enhancements to the Stanford University Mobile IP Linux code and presents performance results obtained through experiments on our test-bed. Finally, we use analysis to accurately quantify the savings in signaling overhead obtained when TeleMIP is used in environments where mobiles change subnets relatively rapidly.

I. Introduction

In recent times, much interest has been generated in developing efficient IP-based mobility management schemes to handle user mobility in cellular networks. Such schemes are necessary to achieve seamless integration of cellular networks with existing IP-based data networks. The standard IP-based mobility management scheme, Mobile IP [1], was primarily designed for transparent support of non-real time data applications.

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Moreover, basic Mobile IP has been shown [2], [3] to be inappropriate for supporting real-time traffic, such as voice and video, which is expected to be an important component in next-generation cellular networks. Various enhancements have been proposed to overcome the shortcomings of basic Mobile IP, e.g., [2], [4], [3], [5], [6].

Telecommunication Enhanced Mobile IP (TeleMIP) [4] is a scalable and hierarchical IP-based architecture that provides lower handoff latency and signaling overhead compared to Mobile IP. TeleMIP is also designed to address additional considerations such as address space limitations in IPv4 and dynamic load balancing. The Intra-Domain Mobility Management Protocol (IDMP) [7] has recently been proposed as a stand-alone protocol for supporting several mobility features, such as minimally interrupted handoff and paging, within the mobility domain. This separation of intra-domain mobility from inter-domain mobility allows IDMP to coexist with multiple alternatives for global mobility management, including Mobile IP and SIP[8]. TeleMIP combines IDMP and Mobile IP respectively for intra-domain and inter-domain mobility management to provide an attractive and scalable mobility management solution for IP-based cellular networks.

In this paper, we discuss our current implementation of TeleMIP and compare its signaling load with that of basic Mobile IP. We present details of our implementation of IDMP, based on enhancements to the Stanford University MosquitoNet [9] basic Linux Mobile IP code. We provide illustrative examples to demonstrate the successful deployment of TeleMIP in our laboratory test-bed and also tabulate some initial performance results.

The rest of the paper is organized as follows. Section II briefly describes the drawbacks of conventional Mobile IP and presents an overview of the TeleMIP architecture. While Section III presents the implementation details of TeleMIP along with the experimental test-bed results, Section IV compares the signaling overhead of TeleMIP with that of basic Mobile IP. Finally, Section V concludes the paper.

II. IP Mobility Solutions and TeleMIP

Mobile IP [1] provides application-transparent IP-based mobility support by maintaining network connectivity while allowing a mobile node (MN) to retain its permanent IP addresses. This is essentially achieved by providing the MN an additional topologically consistent IP address, called the care-of address, in the foreign network. The care-of address thus obtained provides the MN a temporary binding whenever it roams into a foreign network. The MN is responsible for registering this binding with its Home Agent (HA), a stable point of attachment in its home network. The HA is then responsible for forwarding IP datagrams sent by correspondent node(s) (CN) to the MN's permanent home address by tunneling it to the MN's temporary care-of address.

Various extensions and modifications to the basic Mobile IP standard, such as correspondent agent binding in Mobile IPv6 [10] and route-optimization [11] have been proposed. All these schemes employ a flat mobility architecture and consequently suffer from several drawbacks; reference [4] provides a detailed discussion of the shortcomings of such schemes in commercial cellular networks.

Various hierarchical schemes have been recently proposed to improve IP-based support for macro-mobility in cellular environments. For example, both HAWAII [2] and Cellular IP [3] reduce the frequency of high-latency global updates by allowing an MN to maintain a single care-of address while moving within an entire domain. However, both HAWAII and Cellular IP require the establishment of dynamic source-specific routes and operate best in networks with a tree-like topology. Hierarchical extensions of Mobile IP have also been proposed, e.g., [6], [12]. These schemes clearly reduce the frequency of high-latency location updates since the updates are propagated only up to the nearest node in the hierarchy. However, the establishment of multiple levels of hierarchy in a commercial multi-level provider environment introduces significant network management and security issues. TeleMIP tries to achieve a balance between the problems of high update latency and complex management architectures by using a two-level hierarchy.

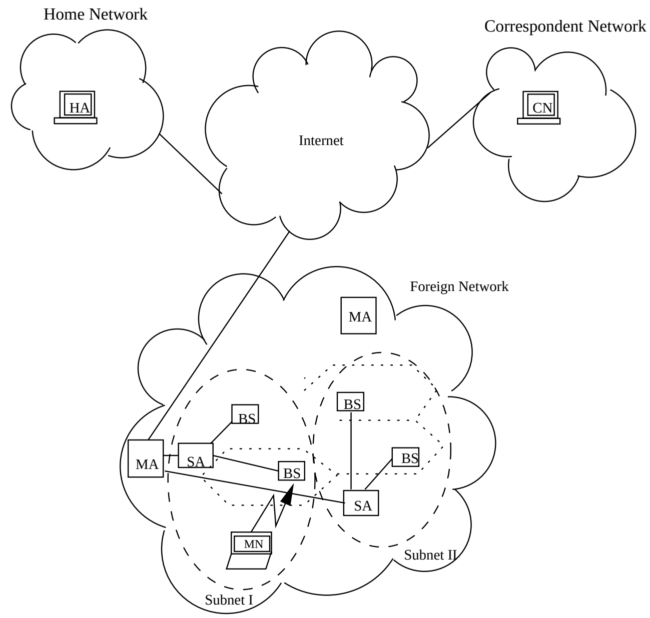

Fig. 1. Functional TeleMIP Architecture

The TeleMIP architecture is illustrated in Figure 1. It specifies a new operational node, the *Mobility Agent* (MA), which resides at a higher level in the network hierarchy than the subnet-based Foreign Agents (FAs) and provides an MN with a global care-of address that is valid throughout the entire domain. Unlike [2] and [3], TeleMIP does not manage intra-domain mobility by using source-specific routes, but uses a second *locally-scoped care-of address* that is valid only with the domain. This local address is assigned by the Subnet Agent (SA) (or relevant DHCP [13] server in the case of co-located care-of addressing) on a subnet and changes whenever a mobile attaches to a new subnet; the MN is responsible for updating the MA whenever it obtains a new local address. Since information about the (frequent) subnet changes is transmitted only locally (up to the MA), these updates have much lower latency and hence enable much faster intra-domain hand-offs. Although TeleMIP's mobility management and packet forwarding mechanisms are similar to [5], we believe that the TeleMIP architecture offers a better load-balancing approach and supports a cleaner security model. A more comprehensive discussion of the TeleMIP architecture is available in [4].

III. Protocol Implementation and Testing

Several implementations of Mobile IP have been developed in recent past, e.g., [9], [12], [14], [15]. The Linux Mobile IP code of Stanford University MosquitoNet project [9] is used as a basis for TeleMIP implementation. The mobility agent daemon of TeleMIP is a modified version of the home agent daemon, while the mobile host daemon has been upgraded to support TeleMIP. The linux kernel at the MA also needed modifications to support additional TeleMIP features, including the establishment of forwarding tunnels between the MA and the MN and also the maintenance of the list of locally registered MN's.

A. IDMP Packet Formats

Mobile nodes under TeleMIP use IDMP to register their local care-of address with the designated MA. While IDMP packet formats and location update messages are based on Mobile IP, they have been modified to support additional intra-domain mobility features. Figures 2 and 3 show the IDMP packet formats for intra-domain registration request and reply messages respectively. Our current implementation supports only the co-located mode for local addressing. An MN thus uses DHCP to obtain a local care-of address; subnet-level registrations (between the MN and an SA) are consequently beyond the scope of this paper. For additional details on the individual message fields, please refer to [7]. Since support for paging and fast handoff is not available in our current IDMP implementation, the corresponding flags (P and O bits) are set to 0.

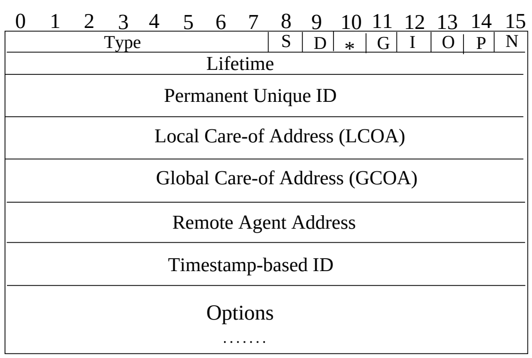

Fig. 2. IDMP Intra-domain Location Update Packet Format

Because Mobile IP is used as the global mobility management protocol, the permanent home IP address is assumed to be the unique identifier for the MN. The MN uses the IP address of its HA in the remote agent address field in its location update message. Like [9], we have provided timestamp-based replay-protection in the location update process, with two distinct timestamps for the local (MN-MA) and global (MN-HA) registrations. Similarly, the security association between the HA and the MN is distinct from the security association between the MN and MA; currently the only authentication method supported being keyed-MD5.

B. Functional Enhancements

The Mobility Agent (MA) handles local registration requests from MNs that are currently in its domain,

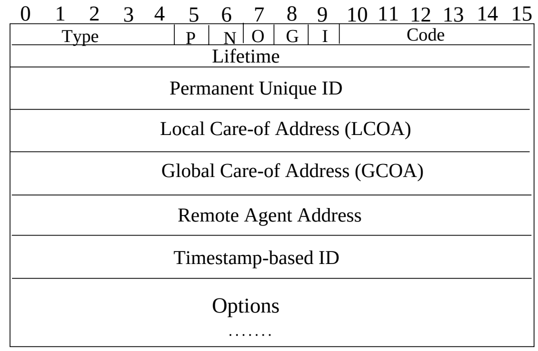

Fig. 3. IDMP intra-domain Registration Reply Packet Format

and provides temporary bindings to the MNs as long as they remain in the domain. As far as the handling of such registration (or location update) requests is concerned, there is little functional difference between HA and MA. Unlike the HA, which has a permanent list of mobility bindings for each MN associated to its home network, the MA maintains a dynamic list of mobility bindings for currently registered MNs. The major functional difference between HA and MA is in terms of packet forwarding to the MN. When the MN is away from the home network, the HA is responsible for collecting all the packets directed at the MN's permanent IP address and tunneling the packets to the global care-of address (which is also the IP address of the MA interface). The task of the MA is simpler; it receives the packets automatically, and after decapsulating the packets, redirects the inner IP packet to the MN's local care-of address. So there are two levels of tunneling involved in TeleMIP, one from the HA to the MA, and the second from the MA to the MN.

Once the MN enters into a foreign network, it receives a local care-of address and the address of its MA interface (which is a globally valid IP address) from the DHCP server. After the two addresses are obtained successfully, the MN first attempts a local registration with the MA using the local care-of address. This local care-of address is valid only within the domain and may thus be privately scoped. After a successful local registration, the MN then attempts to register with the HA with the IP address of MA as its globally valid care-of address. The MN is considered to be registered only after it has successfully performed both the local and global registrations. Subsequently, as the MN changes subnets while remaining in the same domain, the MN performs only a local registration with the new local care-of address. Since the MA address remains unchanged, there is no need to perform a new global registration. Only when the MN changes domains, which is reflected by possibly a new MA address, it performs both registrations again.

TeleMIP does not require any change in the functionality of the HA. In fact, the HA is potentially unaware of the use of IDMP and the presence of the MA. As in conventional Mobile IP, it simply has to intercept all packets intended for the MN from the home network, encapsulate them and forward them to the care-of address specified in the MN-HA registration message. The registration request and reply message formats for global registrations are, in fact, identical to Mobile IP with a single exception: the reserved bit in flags field in [9] is now used to indicate whether the MN is operating in a TeleMIP-based network.

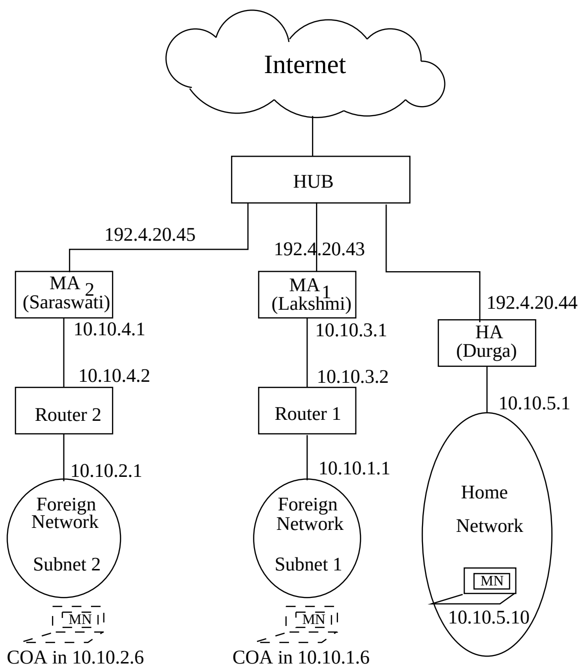

Fig. 4. Test Network Configuration

C. Experimental Validation

Figure 4 shows our experimental network test-bed used for evaluating TeleMIP. We considered a single MN served by its HA (Durga=192.4.20.44) in its home network 10.10.5.0, with home IP address 10.10.5.10. The home interface address of Durga is 10.10.5.1. Two MAs, viz., MA_1 (Lakshmi=192.4.20.43) and MA_2 (Saraswati=192.4.20.45) are connected to routers serving subnets 10.10.1.0 and 10.10.2.0 respectively. We assume that our mobility domain comprises both subnets 10.10.1.0 and 10.10.2.0. Accordingly, both Lakshmi and Saraswati can serve as mobility agents for our MN as long as it stays within this domain.

As the MN enters into the subnet 10.10.1.0, it receives a locally scoped co-located address 10.10.1.6 and the IP address of MA_1 (192.4.20.43) as its global care-of address. The MN accordingly first informs MA_1 of its local care-of address (10.10.1.6) and subsequently registers with the HA using 192.4.20.43 as its care-of address. Afterwards, the MN roams into the subnet 10.10.2.0 and gets a new local care-of address 10.10.2.6. Since MA_1 is still its MA, the MN simply performs an intra-domain location update, informing MA_1 of its new local care-of address.

To test the case of inter-domain mobility, we subsequently configured the DHCP server to provide a new MA address, MA_2 (Saraswati=192.4.20.45), to the MN. In this case, the MN performs both the intra-domain and global registrations. Figure 5 illustrates the mobility bindings in the HA (Durga) and the MA_1 (Lakshmi) when the MN (with home address 10.10.5.10) is attached to the 10.10.1.0 subnet (with a local address 10.10.1.6) with an MA address of 192.4.20.43.

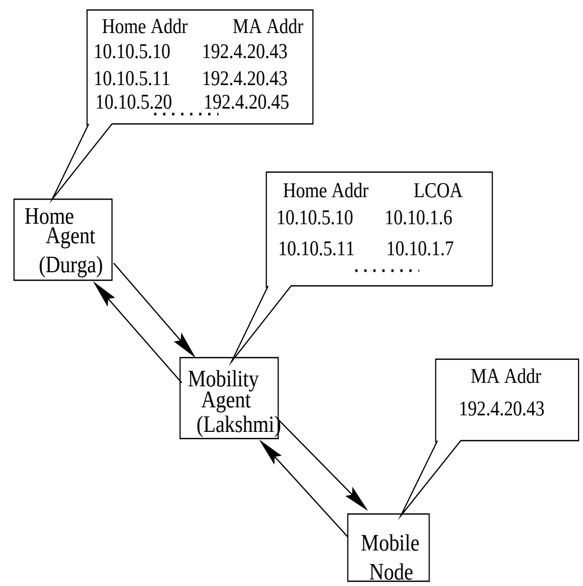

Fig. 5. Status of Binding Tables in HA and MA in a Typical Scenario

D. Experimental Forwarding Latency

The TeleMIP architecture introduces an additional layer of decapsulation and encapsulation (at the MA) in the forwarding path. Since it would be interesting to ascertain the effect of this additional processing on the forwarding latency, we collected statistical data by pinging the MN using its home IP address 10.10.5.10 as it roamed in the various subnets with different MAs. The correspondent node (CN) in each case was the HA (Durga). Results for the average round-trip latency are provided in Table I; the first row corresponds to the case when the MN was using conventional Mobile IP (in the co-located mode). Clearly, the additional processing at the MA increased the round-trip latency with TeleMIP. This delay was of the order of $2-3$ *msecs* and is probably due to the relatively slow speed (90Mhz) of

TABLE I

PING STATISTICS FOR THE MOBILE NODE

Local COA	Current MA	Average round-trip delay *(msec)*
10.10.5.10	None	0.4
10.10.1.6	Lakshmi	3.8
10.10.2.6	Lakshmi	7.3
10.10.2.6	Saraswati	1.5
10.10.1.6	Saraswati	8.4

our hosts. The table also shows how intra-domain triangular routing (when the MA is not on the optimal path from HA to MN) can increase the round-trip latency. The difference in delay for the same number of hops can probably be attributed to differences in the processing capability of the individual MA and routers.

IV. Analysis of Signaling Overhead

In this section, we compare the signaling overhead associated with TeleMIP with that of basic Mobile IP. We use the following parameters to express the signaling overhead of both TeleMIP and Mobile IP:

- $L_g = 46$: Size of global registration packet (in bytes).
- $L_l = 50$: Size of local registration packet (in bytes). (Note that $L_g < L_l$, since the global registration request does not contain the local care-of address field.)
- T_s: Average duration for which MN remains in a subnet (secs/subnet).
- T_d: Average duration for which MN remains in a domain (secs/domain).
- N: Average number of subnets in a domain.
- $N_{MA} = 2$: Average number of hops from MN to MA when the MN is in foreign network.
- $N_{HA} = 5$: Average number of hops from MN to HA when the MN is in foreign network.
  (2 and 5 are arbitrary numbers)

Clearly, T_s and T_d depend on the network topology and the mobility pattern of the MN. For the sake of simplicity, in our analysis we assume $T_d = NT_s$. In Table II, the expressions for signaling overhead in basic Mobile IP and TeleMIP are outlined in terms of the parameters listed above. In each expression, the factor of 2 is due to the fact each registration attempt involves exchange of a registration request and a corresponding reply message.

The global and local signaling overhead per hop in TeleMIP against T_s for different values of N is plotted in figure 6. As expected, global signaling overhead in TeleMIP is significantly less than local overhead in TeleMIP. Also the signaling overhead goes down as the

TABLE II

EXPRESSIONS FOR SIGNALING OVERHEAD

Architecture	Signaling Overhead *(bytes/sec)*		
	Local per hop	Global per hop	Total in Network
Mobile IP	0	$2L_g/T_s$	$2N_{HA}L_g/T_s$
TeleMIP	$2L_l/T_s$	$2L_g/T_d$	$2N_{HA}L_g/T_d + 2N_{MA}L_l/T_s$

MN stays longer in a subnet (and domain). As the number of subnets in a domain increases, the global signaling overhead reduces whereas the local signaling overhead remains unchanged. In other words, global signaling overhead in basic Mobile IP and local overhead in TeleMIP does not depend on N.

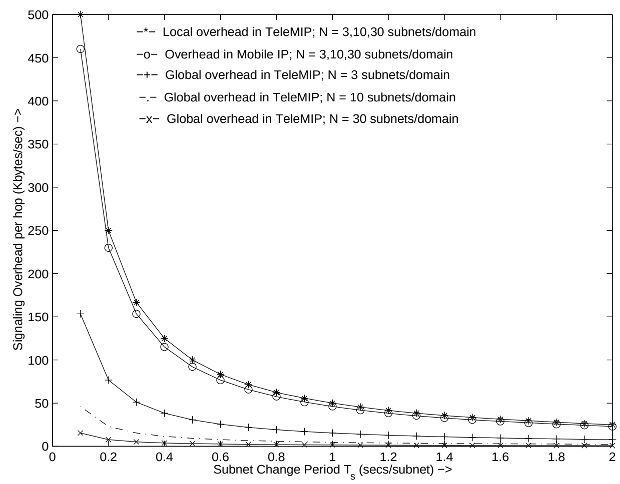

Fig. 6. Global and Local Signaling Overhead in TeleMIP

Since global signaling messages travel over a larger number of hops (and hence consume a larger portion of network resources), we would also like to compare TeleMIP and Mobile IP in terms of the total network capacity (aggregated over all hops) used. Figure 7 shows this total network signaling overhead for both TeleMIP and Mobile IP as N is varied. The plots clearly show that TeleMIP results in a significant reduction in the network signaling overhead, especially when mobiles change subnets more frequently and when larger number of subnets form a single domain.

Finally, figure 8 shows total signaling message overhead for Mobile IP and TeleMIP as N_{HA} is varied. In this plot, we consider the number of subnets in a domain (N) is 10 and the number of hops to the MA (N_{MA}) is 2, which are fixed. The plots once again depict that the total signaling overhead in TeleMIP is significantly less compared Mobile IP and as N_{HA} increases, this differnce becomes larger and larger.

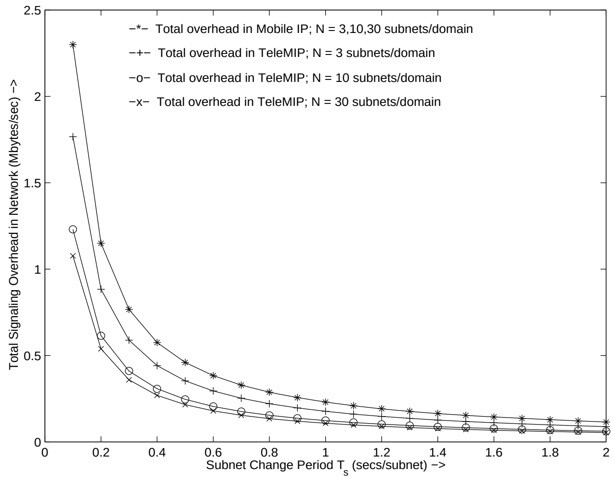

Fig. 7. Total Network Signaling Overhead

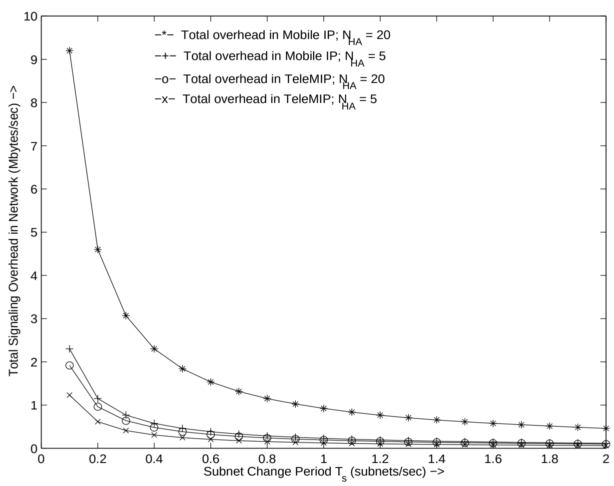

Fig. 8. Total Network Signaling Overhead

V. Conclusion

In this paper, we discussed our prototype design and implementation of the TeleMIP architecture for IP-based mobility management. Our implementation of the MA and MN are based on modifications to Stanford University's MosquitoNet Project Linux code. We demonstrated the basic operation of TeleMIP in our test-bed and presented some experimental results. We also used standard packet formats to quantitatively compare TeleMIP's signaling overhead with that of Mobile IP.

In [7] and [16], we have introduced several additional features for intra-domain mobility management, such as paging and fast handoff support. We have also recently developed a framework [17] for supporting QoS guarantees in the TeleMIP infrastructure. We expect to incorporate these additional features in our future implementation and study their performance in our test-bed in greater detail. Currently the prototype operates only in the co-located mode, and hence requires DHCP support. Work is in progress to incorporate subnet agent (SA) support as well. A more comprehensive analysis and comparison of TeleMIP with other existing protocols with respect to update latency and fast intra-handoff are our next goals.

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