P2P systems are service-oriented and have evolved mainly over different communities and addressed entirely different requirements. The short-term and small-scale architecture. P2P-MANET (P2P over MANET) is used to describe the cross-layer architecture, which detects the network dynamics and peer movement to support a communication with high delivery ratio. The ring overlay is used to utilize simply, stabilize real-time delivery, and minimize signaling overhead. The characteristics of self-organization and decentralization share the network load and help the network scalability for MANET. Although the traditional P2P system falls into imprropriety and inefficiency of real-time distribution on MANET, RING can achieve the acceptable quality in short-term and small-scale purpose. We discuss the comparison of overlay performance and demonstrate that RING is workable via the mathematical theory and a series of experiences. RING can deal with peer arrival and departure quickly and simply to shorten the service interruption time with minimal signaling overhead.

Keywords
P2P-MANET; Cross-layer design; Wireless ad hoc; P2P voice communicating; Real-time multimedia service

Abstract
This paper presents RING, a novel peer-to-peer (P2P) voice communicating system on mobile ad hoc network (MANET). RING proposes a ring overlay, a set of protocols, and an implementation enabling the delivery voice among peers without connecting to Internet. The logical overlay is proximal to the physical topology based on cross-layer scheme, which detects the network dynamics and peer movement to support a communication with high delivery ratio. The ring overlay is used to utilize simply, stabilize real-time delivery, and minimize signaling overhead. The characteristics of self-organization and decentralization share the network load and help the network scalability for MANET. Although the traditional P2P system falls into imprropriety and inefficiency of real-time distribution on MANET, RING can achieve the acceptable quality in short-term and small-scale purpose. We discuss the comparison of overlay performance and demonstrate that RING is workable via the mathematical theory and a series of experiences. RING can deal with peer arrival and departure quickly and simply to shorten the service interruption time with minimal signaling overhead.

Keywords
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Introduction
Recent advance in wireless technology and mobile computing has provided a major development of mobile ad hoc network (MANET). In MANET, two mobile nodes can communicate with each other through other intermediate nodes over wireless infrastructure-less network without the centralized administration. A decentralized approach like peer-to-peer (P2P) computing can be an appropriate solution adopted in the self-organized environment. The P2P application usually has a specific purpose for the cooperative voice communication, so the cross-layer scheme is utilized to optimize the short-term and small-scale architecture. P2P-MANET (P2P over MANET) [1] is used to describe the cross-layer architecture, which provides the real-time communication in disaster areas and battle fields without high cost or long setup time of system installation.

However, P2P and MANET techniques have been developed by different communities and addressed entirely different requirements. P2P systems are service-oriented and have evolved mainly over the wired Internet so far, and they serve large amount of users in global scale for a long term. By contrast, MANET is spontaneous, infrastructure-less wireless networks for mobile terminals, and it serves small amount of users in local scale for a short term. Therefore, the cross-layer scheme is difficult to support voice communication due to the innate disadvantages: (1) MANET degrades the maintenance of P2P overlay due to the frequent mobility problem. (2) P2P overlay is not proximal to MANET topology, this leads to the inefficient streaming delivery. (3) The unreliable wireless connection leads to the out-of-order congestion of multi-source P2P voice communicating.

This paper presents Real-time Intercommunication Network Gossip (RING) to overcome the above drawbacks. RING is a voice communicating application on P2P-MANET. Mobile nodes as peers collaborate with each other on a ring overlay without the centralized server. RING integrates P2P overlay into the cross-layer scheme to manage the ad hoc topology. Through P2P overlay, a virtual conferencing room can be formed in the short-term and small-scale purpose. The users can communicate together in the infrastructure-less environment without through Internet, hence the implementation of handed device equipped with RING can be used for the disaster rescue. The ring overlay can deal with peer arrival and departure fast and simply to shorten the service interruption time with minimal signaling overhead. The implement of application neither considers the complex voicing mixer nor the connection-oriented delivery.

The paper is organized as follows: Section 2 presents the related works. Section 3 introduces the voice communication on RING and illustrates our proposed cross-layer scheme. Section 4 presents the analytic performance of voice communication on P2P-MANET. In Section 5, the simulated results demonstrate that our proposed scheme works well via the measurement of packet delivery ratio and signaling overhead. Section 6 concludes the paper.

Related Works
In general, the cross-layer design of P2P-MANET can be described as Figure 1. The P2P protocol integrates with the ad hoc routing protocol to achieve mobility. The P2P protocol, routing protocol, and cross-layer design are discussed in the followings.

![Figure 1: The network stack of cross-layer P2P-MANET.](http://dx.doi.org/10.4172/2324-9307.1000106)
P2P protocol

The traditional P2P technology uses the distributed hash table (DHT) to apply for file sharing. The fast and accurate searching ability of DHT algorithms is workable attractively for different kinds of applications in wired networks. Chord [2] is a famous example of ring-based DHT, which is used to index peers and files. Chord uses the consistent hashing function to map keys to peers in the static domain, and every peer can locate itself or query any peer depending on the hashing key. However, DHT is unstable for MANET due to the mobility and the locality [3]. Therefore, the studies modify DHT scheme and design the cross-layer integration of P2P overlay and ad hoc routing protocol to improve the delivery efficiency in MANET [4-6].

Routing protocol

The cross-layer design must consider the ad hoc routing protocol to complete a specific purpose of P2P application [7]. The routing protocols for MANET can be classified into reactive and proactive routing protocols. In proactive or table-driven routing protocols, such as Optimized Link State Routing (OLSR) [8], every mobile node maintains a routing table with the global information of network topology. The reactive or on-demand routing protocols, such as Dynamic Source Routing (DSR) [9], every mobile node finds a routing path only when it is necessary. However, these routing protocols are unstable for the real-time service with high data rate due to long delay and high overhead.

Virtual Ring Routing (VRR) [10] adopts the ring-based routing to shorten the end-to-end delay and reduce the message overhead. VRR is an ad hoc routing protocol inspired by DHT, and it organizes the mobile nodes in a unique virtual ring which is independent of physical location. Each node maintains a small number of routing paths to its neighbors in the ring without any flooding scheme. VRR is suitable for P2P application due to its inheritance from DHT. However, its virtual ring is not proximal to the physical topology, so VRR has the far routing problem and serious hidden terminal problem, and VRR is unsuitable for real-time voice communication.

Cross-layer design

Audio Conferencing Testbed (ACT) [11] is based on OLSR to set up a meeting for group of people in WiFi MANET. ACT uses the minimum spanning tree to minimize the latency of audio dissemination to the whole network. Every peer must maintain its minimum spanning tree to deliver data by itself. ACT predicts the disconnection and mobility to shorten the service interruption time.

Cross-Layer and P2P based Solution (CLAPS) [12] is based on the combination of tree-based overlay and OLSR extension. CLAPS assumes that the physical routing topology can be provided by OLSR, which sends cross-layer message to optimize overlay. The source peer maintains a minimum spanning tree as its overlay. The minimum cost is computed via link distance packaged in cross-layer message, and the spanning tree is recomputed periodically to keep the overlay proximity.

Explicit Cross-Layer (EXL) [13] is implemented in the combination of Chord and OLSR. EXL proposes a cross-layer method to merge the ad hoc network triggered by P2P layer. MeshChord [14] is based on the combination of Chord and DSR. MeshChord proposes a cross-layer method to speed up the lookup operations by exploiting the information which is available at the media access control (MAC) layer due to the one-hop broadcast.

In summary, the cross-layer schemes can improve proximity and predict mobility. They combine the characteristics of P2P overlay protocol and ad hoc routing protocol to deliver the multimedia stream efficiently. However, the above methods consider neither multi-source delivery nor sequential voice receipt. The proposed RING not only keeps the advantages of cross-layer design but also considers the multi-source delivery and sequential voice receipt.

Our Proposed Scheme

We propose a new cross-layer scheme to overcome the difficulty of voice streaming for P2P network over MANET. A group of users can chat together when they walk or deal with other thing simultaneously. In our scheme, RING, all peers self-organize a ring overlay to simplify the maintenance of the P2P overlay. Due to the cross-layer integration, an immediate forwarding with proximity can hasten the in-time data delivery.

Overview

To construct the ring overlay, the underlay network dynamics, such as the topology and available bandwidth, must be known, such that the cross-layer information can be used for promoting the routing efficiency. We illustrate the establishment of RING as Figure 2 shown.

First, MANET allows the mobile nodes equipped with ad hoc adapter building a cooperative network. Each mobile node maintains

![Figure 2: Relationship between the ring overlay and the physical topology.](image-url)

1 Chord uses ring-based DHT to achieve multi-hop querying; our proposed scheme, RING, uses ring-based overlay to achieve one-by-one real-time delivery. They are entirely different.
2 Each peer has a link to its predecessor and successor according to the DHT of Chord called finger table.
3 A lot of computing cost and bandwidth is required to maintain the dynamic routing tables in proactive routing; the larger delivery delay is inefficient for heavy traffic in reactive routing.
4 VRR uses ring-based routing in network layer; RING uses ring-based overlay in application layer. They are entirely different.
5 Proactive routing floods on topology change; reactive routing floods to discover routes.
a routing table to know local topology and establish the point-to-point connection in ad hoc model. The voice data can be delivered via a point-to-point connection through multihop routing in an opportunistic network [15]. The users in a group must coordinate a Group ID to login the application, thus RING groups users via the Group ID. RING peers are the mobile nodes using RING application with the same Group ID.

Next, the peers organize themselves via a ring overlay to deliver live voice. Every peer only knows its front peer and rear peer in RING. Whenever a peer joins or leaves, it notices its neighbors actively. Every peer sends Probe Message to its front peer and rear peer periodically to estimate round trip time (RTT), which also indicates the movement, available bandwidth, and absence. As a result, the P2P overlay can be mapped to the physical ad hoc topology in our proposed scheme. Every peer is just responsible to forward voice data to its rear peer without handling data scheduling, peer adaptation, and multiple sources, so the algorithm complexity and the signaling overhead can be reduced.

Third, the peer creates voice data and delivers it on demand instead of maintaining a connection for VoIP. As Figure 2 shown, once the new arriving peer joins one by one via the same Group ID, every peer should connect to two nearest peers and forwards voice data. When user A speaks, the voice data with peer A’s ID is forwarded to every peer in order. Every peer checks the Peer ID to decide whether the voice data is forwarded. The direction of voice stream is from peer F to peer R.

Peer arrival

As Figure 3 shown, the set of peer F, peer L, and peer R is a part of the proposed ring overlay. The direction of voice stream is F \( \rightarrow \) L \( \rightarrow \) R. When a new peer (peer N) launches RING to indicate to join into P2P overlay, peer N must contact someone as linkage peer, whose helps peer N to complete the arrival process because a new peer does not know any P2P overlay and friendship. If peer N contacts its linkage peer (peer L), peer L introduces its front peer (peer F) and its rear peer (peer R) as the candidates to peer N. And then peer N decides to insert between peer L and peer R, because the distance between peer N and peer R is shorter than the distance between peer N and peer F. Next, peer N notices the decision to peer L, and peer L coordinates peer R to become the rear peer of peer N.

We give a detailed explanation to clarify the diagram of peer arrival. As Figure 4 shown, the new peer passes several exchanges of messages to complete the process.

![Figure 3: Diagram of new peer arrival.](image)

![Figure 4: Message flow of new peer arrival.](image)

1. The direction of voice stream is F \( \rightarrow \) L \( \rightarrow \) R. Peer L only keeps the information about peer F and peer R.
2. The new peer (peer N) searches the peers who have the same group ID via Request Message and Response Message.
3. Peer N selects its linkage peer via Probe Message and Probe Ack Message. The new peer selects its linkage peer depending on RTT.
4. Peer N contacts to peer L as its linkage peer via Link Message and Link Ack Message. Link Message brings the information about the candidates. (i.e. the front peer and the rear peer of the linkage peer).
5. Peer N sends Probe Message to the candidates (peer F and peer R) to ensure that the candidates are connectable.
6. Peer F and peer R return Probe Ack Message to peer N. We assume that peer N receives Probe Ack Message from peer R earlier than the message from peer F.
7. Peer N decides to connect peer R due to the short time interval between Probe and Ack. Peer N sends Decide Message to peer L to insert the path.
8. The linkage peer resets its front peer or rear peer, and sends Connect Message to peer N and peer R to set or reset their front peers and rear peers.
9. The direction of voice stream is F \( \rightarrow \) L \( \rightarrow \) N \( \rightarrow \) R. The arrival process is completed.

In ring overlay, every peer always interacts with only two peers, so the singling overhead is low. The packets are delivered sequentially and the multi-source problem is solved due to unidirectional service.
forwarding path. As Figure 5 shown, we illustrate the detailed message flow between the new peer and the linkage peer during the arrival process. In position 1, if two nodes detect each other, a WiFi awareness is updated; otherwise, the new node is indicated to join the ring overlay through intermediate hops. In position 2, if the new node gets a WiFi awareness, it sends Request Message in its transmission range; otherwise, the new node floods Request Message across the entire ad hoc network. The new node receives Response Message for P2P awareness, and this means there are other nodes using the same group ID in the ad-hoc network. Next, the new peer multicasts Probe Message to the nodes who return Response Message. The RTT is the time interval between sending Probe Message and receiving Probe Ack Message. The new node selects the linkage peer with the shortest RTT, and then the new peer joins successfully after the completeness of Link Message and Decide Message. The proposed cross-layer scheme performs time sensitivity of neighborhood, so such scheme of peer arrival is efficient with scalability and proximity.

Peer departure and movement

When a peer leaves the P2P network, it voluntarily informs its front peer and rear peer via a Left Message so that they can recover the ring overlay. The purpose of Left Message is to let the front peer and the rear peer can find each other quickly. After receiving Left Message, the peers send Connect Message to each other for the confirmation of connectivity. When the original delivery path is broken due to peer departure, the new delivery path is established as Figure 6a shown. However, Left Message may get lost, or the peer leaves before exchanging Connect Message. The original delivery path is broken as Figure 6b shown. Therefore, in our proposed scheme, every peer multicasts periodically Probe Message to maintain indirectly P2P overlay and monitor the neighbors’ movements. When the rear peer (peer R) finds out the disappearance of its front peer (peer L), it floods Finding Message, which includes the peer L’s ID, to all peers in the ad hoc network. Peer F receives Finding Message and knows that the peer L is its rear peer, and then Peer F exchanges with peer R for Connect Message to establish a new delivery path.

Because every peer only knows its front peer and rear peer, it cannot gain the neighboring information like global position system (GPS). Therefore, a peer indicates its neighbor moving via the reactive leaving. As Figure 7a shown, after peer M starts to move, neither peer C nor peer D probes to peer M gradually. Peer C and peer D think that peer M should leave or move, peer D disconnects from peer M and then connects to peer C as Figure 6b. Thus peer M becomes an orphan and then finds a linkage peer as Figure 3. As Figure 7b shown, peer M finds peer A as a linkage peer and joins into the overlay.

In summary, RING adopts a ring overlay to manage peers simply, overcome multi-source difficulty, deliver voice in order, and minimize signaling overhead. The ring overlay is integrated with a cross-layer scheme to allocate peer arrival, detect peer movement, and recover peer departure, with efficiency, scalability, mobility, and proximity.

Analysis

Packet delivery ratio

Suppose the probability of failed forwarding is \( f \) in every peer, and there are \( n \) peers in the routing path \( N \). The probability of successful delivery in \( N \) is \( P(N) \).

\[
P(N) = (1 - f)^n \tag{1}
\]

And the probability of unsuccessful delivery is \( 1 - (1 - f)^n \).

There may be two routing paths on the same overlay. Suppose there are \( m \) peers in another routing path \( M \). If \( N \) is disjoint to \( M \), i.e.
The Bernoulli formal can be applied to an analog of Poisson process in a continuous time. We can define that the rate of packet created is \( \lambda \) in a given time \( t \). The probability that \( z \) peers create voice packets in \( t \) is \( P_z(t) \).

\[
P_z(t) = e^{-\lambda t} \left( \frac{\lambda t}{1!} \right)^z / z!
\]

while \( \lambda t = E_z(h) \times p \) \( \) (11)

Therefore, the expected value of duplicated packets is simplified as \( E_z \).

\[
E_z(n) = \sum_z P_z(z, t) \times z \times n
\]

(12)

The fixed \( \lambda, t, n \) can derive the \( E_z(n) \) for the low bound of packet duplications in the proposed ring-based forwarding scheme.

**Simulation Results**

We use OMNet++ \[ 16 \] to simulate. In random waypoint model, we define every wireless node with parameters \( (x, y, \pi, v, s) \) in a simulation environment \( (1000 \times 1000 \) square meters area) as Figure 8 shown. The parameters \( (x, y) \) represent the coordinate of a node in

\[
\text{Figure 8: The simulation environment.}
\]

Table 1: The parameters of simulation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type</th>
<th>Range</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x )</td>
<td>natural number</td>
<td>0 - 1000 m</td>
<td>random</td>
<td>x-axis</td>
</tr>
<tr>
<td>( y )</td>
<td>natural number</td>
<td>0 - 1000 m</td>
<td>random</td>
<td>y-axis</td>
</tr>
<tr>
<td>( \pi )</td>
<td>decimal</td>
<td>0 - 360(^\circ)</td>
<td>random</td>
<td>moving angle</td>
</tr>
<tr>
<td>( v )</td>
<td>natural number</td>
<td>0 - 128 km/h</td>
<td>0</td>
<td>moving speed</td>
</tr>
<tr>
<td>( s )</td>
<td>binary number</td>
<td>true of false</td>
<td>false</td>
<td>turn on or not</td>
</tr>
<tr>
<td>( n )</td>
<td>natural number</td>
<td>4 - 40</td>
<td>32</td>
<td>number of peers</td>
</tr>
<tr>
<td>( f )</td>
<td>real number</td>
<td>0 - 1</td>
<td>0.02</td>
<td>failed probability</td>
</tr>
</tbody>
</table>

\[
\text{Figure 9: The amount of voice copies increases with the number of peers.}
\]

\[
\text{Table 1: The parameters of simulation.}
\]
the simulation square. \( \pi \) represents the moving angle of each node. If a node crosses the simulated boundary, \( \pi \) becomes a reflective angle as node \( b \) to ensure that every node moves in the simulation square. \( v \) represents the moving speed of each node. When \( v = 0 \), it means the node is static as node \( c \). If \( s = \text{true} \), the node is a member of P2P overlay as node \( a \), otherwise, the node is just a member of MANET topology as node \( c \). We list the parameters in Table 1.

RING can be implemented on either reactive routing protocol or proactive routing protocol. In the paper, RING is implemented on OLSR to compare with ACT and CLAPS, which both are implemented on OLSR, too. We use INETMANET [17] module based on OMNet++ to simulate OLSR. We also use WiFi ad hoc mode and CTS/RTS mechanism to simulate MAC behaviors. Because three compared methods use the same ad hoc routing protocol and MAC protocol, the simulated performance is influenced by the P2P overlay and cross-layer scheme.

Scalability

Scalability is an essential characteristic of both P2P network and MANET. We sum up the amount of copies of voice data which are transmitted through the ad hoc network as Figure 9 illustrated. We can find out that RING, ACT, and CLAPS all have the similar performance, thus P2P solution can be demonstrated in an efficient delivery with scalability. Especially, RING has the performance approximated to an ideal \( E(n) \) as Equation 12, because every peer only copies once for its rear peer and every intermediate node only copies once for the destination.

The packet delivery ratio is defined as the ratio of voice packets received by the destination to those generated by the source. Assume the probability of failed forwarding (\( f \)) is 0.02, the worst packet delivery ratio as Equation 5 can be derived with scalability. As Figure 10 illustrated, RING has the highest packet delivery ratio among all compared models. The delivery path is directive in order uniquely, hence RING is suitable for the wireless half-duplex connections. However, the large network leads to the long routing path, which leads to low packet delivery ratio. ACT and CLAPS have the low packet delivery ratio, because the collision happens in the overlap of spanning trees when many peers simultaneously speak. Especially CLAPS overlay tends to share the overlapping routing path, thus its packet delivery ratio degrades seriously with scalability.

We define the signaling overhead as the number of non-data packets sent per peer per second for maintaining overlay. As Figure 11 illustrated, RING have a minimum signaling overhead, because a peer only keeps its front peer and rear peer via periodical probing. A peer has more signaling overhead when the overlay is larger in ACT and CLAPS, because the spanning tree grows with the scalability.

We observe the in-order packets received by receiver as Figure 12 illustrated, in which x-axis represents the simulated time and y-axis represents the timestamp or sequence number. The sequential receipt is important for voice service, and RING always keeps packet in order, because the ring overlay inherits the advantage of
first-in-first-out delivery in essence. However, RING uses a unique overlay, in which front peer always forwards packets to rear peer, so a forwarding failure leads to a continuous loss. Although CLAPS also has continuous loss which happens due to a collision in the overlap of spanning trees. Both ACT and CLAPS have some out-of-order packets accompanied loss, because packets are delivered individually through their spanning trees, which do not guarantee the sequential delivery from multiple sources.

Mobility

Mobility is an essential characteristic for group conferencing on MANET. We set 32 peers, randomize $\pi$ and increase $v$ to simulate the peer moving. The simulation result is curved in Figure 13, and we can discover that RING has the highest packet delivery ratio among the compared models. The cross-layer scheme detects peer movement and modifies a ring overlay to avoid the far routing path. The cross-layer scheme always performs time sensitivity of neighborhood to keep proximity. Every peer keeps only two neighbors, so the overlay recovery spends minimum time and overhead. The integration of cross-layer scheme and ring overlay in RING achieves the low signaling overhead as Figure 14 illustrated. However, every peer must maintain its spanning tree in ACT or CLAPS, thus the signaling overhead is high with mobility. Also the multiple sources with high mobility degrade the packet delivery ratio, because their spanning trees are difficult to maintain.

As Figure 15 and Figure 16 illustrated, in RING, even if the ring overlay changes, the moving peer always influences only two neighbors (its front peer and its rear peer). Therefore, the low speed does not cause the high packet loss. However, the high speed changes the overlay drastically, which leads to the continuous and frequent packet loss. Although packet delivery ratio is degraded with moving speed, RING still keeps the sequential receipt. Because the ring overlay inherits the unidirectional stream, the voice arrives in order even if multiple peers speak simultaneously.

A peer movement may break a routing path. From the observation of packet loss, RING is demonstrated for a short service interruption time. However, ACT and CLAPS have the large packet loss and out-of-order receipt, because their overlays is difficult to maintain. The recovery of spanning tree usually influences multiple peers when single peer moves, so the service interruption time is long due to high scalability and mobility.

Conclusion

In this paper, we design an application for voice communication over mobile ad hoc network. And we present a cross-layer scheme to integrate the ring overlay and mesh-based topology. The implement shows that our proposed scheme, RING (Real-time Intercommunication Network Gossip), is simple to work and suitable for small-scale conference. The simulation results show that RING has the high packet delivery ratio and the low signaling overhead, that demonstrates RING is suitable for the real-time voice delivery. The logical overlay of RING can be proximal to the physical topology based on cross-layer design. Hence, the combination of algorithms of peer arrival, movement, and departure can provides a stable routing path in dynamic ad hoc network. From simulation results, packets always arrive in order in RING, which is suitable for the wireless half-duplex connections to alleviate the multi-source problem. In the future, we consider a double-ring overlay and an admission control to save energy and shorten packet delay.

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