Node-Stamping Approaches to Efficient Message Broadcasting in Wireless Ad Hoc Networks

Chun-Hsin Wu and Chia-Wei Li

Abstract—**In wireless ad hoc networks, the node communicates with each other directly by message broadcasting. Since there is no pre-defined infrastructure, the messages flooded by broadcasting may cause a serious broadcast storm problem. To improve broadcast efficiency, we propose node-stamping approaches that introduce the stamp list to track up-to-date visited nodes and their neighbors to prune more redundant-messages. In addition, we develop stamp reduction and compression techniques to reduce the cost of node stamping. Compared with previous methods, the simulation results show that the node-stamping approaches improve broadcast efficiency further with reasonable stamp cost.**

Index Terms—**Ad hoc networks, broadcast storm, identity stamping, and path tracking.**

I. Introduction

Wireless ad hoc networks are the networks in which the nodes communicate with each other directly using wireless connections without the need of pre-defined infrastructure [1]. By self-configuring, the nodes of an ad hoc network quickly form a dynamic network with less configuration and maintenance costs. The features of minimal configuration and easy deployment make ad hoc networks suitable for a variety of applications that have no central nodes or cannot rely on them.

In wireless ad hoc networks, each node has a transmission range and the nodes lived within the transmission range are regarded as its neighbor nodes [2], [3]. To send a message to other nodes, a node broadcasts the message to its neighbor nodes, and each node receiving the message determines whether to forward the message [4]. This kind of message broadcasting is one of the fundamental operations in wireless ad hoc networks to support route discovery, route maintenance and topology update in many routing protocols.

In the absence of an appropriate strategy, a node in the wireless ad hoc network may transmit many redundant messages and waste considerable power. Besides, signal collision may occur substantially since the nodes are likely to transmit more packets for the redundant messages over the same wireless channel at the same time. Once signal collision occurs, it makes the collided packets being lost and consequently reduces the number of nodes that successfully receive the message.

Flooding is an intuitive broadcasting method that a node rebroadcasts every received message to its neighbor nodes. This method guarantees that a flooded message can reach all connected nodes if there is no collision. However, it causes the serious broadcast storm problem because all nodes rebroadcast the same message resulting in the network with full of duplicate messages [5]. In order to solve these problems, many enhanced broadcast algorithms including probability-based methods, area-based methods and neighbor knowledge methods have been proposed to improve the efficiency of broadcasting in wireless ad hoc networks [6].

In this paper, we propose node-stamping approaches to broadcasting messages efficiently in wireless ad hoc networks. In these stamping-based approaches [7], every message is associated with a stamp list and every node appends its identity and other information to the list for the broadcasted message. The stamp list tracks the visited nodes of the message, and depending on stamping strategies, the list also records other possible visited nodes such as the neighboring nodes. When a node receives the message, it will examine the stamp list to decide if it needs to rebroadcast the message. The simulation results show that node stamping can improve broadcast efficiency significantly, but the size of the message increases as hops of forwarding nodes also increase. To tackle this problem, we propose several techniques to reduce the stamping overhead as well.

The rest of this paper is organized as follows. Section II introduces the background knowledge and related works. We present the proposed stamping approaches in Section III and the techniques to reduce the stamping cost in Section IV. Section V shows the analysis and simulation results. Section VI concludes the work.

II. Related Works

Message broadcasting is a simple mechanism for nodes of wireless ad hoc networks to communicate with each other. Usually there are four categories for broadcast methods based on the information utilized: flooding methods, probability-based methods, area-based methods and neighbor knowledge methods.

A. Flooding Methods

For broadcasting, blind flooding (BF) is a simple method whose node broadcasts a new or received message to its neighbor nodes. To prevent broadcast storming, hop limiting and message recording are two common techniques to enhance blind flooding. By hop limiting, the message includes the maximum hop count to restrict the number of hops that the nodes can broadcast the message and decrease the count only if it is non-zero.

To reduce the redundancy further, the nodes record every

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C. H. Wu and C. W. Li are with the Department of Computer Science and Information Engineering, National University of Kaohsiung, Kaohsiung, Taiwan (e-mail: wuch@nuk.edu.tw).

received messages and only broadcast the new messages. The same message is broadcasted exactly once by each node and it stops when all reachable nodes have broadcasted the message. This guarantees that every message arrives to all reachable nodes in the network by broadcasting if there is no collision. Since it is simple and effective, simple flooding usually works in practice in wireless ad hoc networks with low node density or high node mobility.

B. *Probability-Based Methods*

Probability-based methods such as probabilistic schemes and counter-based schemes use very limited network information to provide a probability for nodes to consider whether to rebroadcast a message. Probabilistic schemes work like simple flooding except that each node decides whether to rebroadcast a message with a pre-defined probability [5]. Simple flooding is the special case when the probability of probabilistic schemes is one.

Instead of making decisions immediately with a probability, counter-based schemes use a threshold for each node to determine whether to rebroadcast a message. On receiving a new message for the first time, a node schedules a random assessment delay (RAD) [6], and a counter for the message is increased by one for each duplicate message the node received during the RAD. After the RAD expires, the node forwards the message if the counter is less than a pre-defined threshold value.

C. *Area-Based Methods*

Area-based methods such as distance-based schemes and location-based schemes use distance or location information between the source node and the receiving node to ensure that each node can cover sufficient additional area [7].

For each node of distance-based schemes, it evaluates its distances to the other nodes by using signal strengths from previous transmission. Instead of counting the number of duplicate messages during the RAD, the node estimates the minimal distance between itself to the nodes that broadcast the duplicate messages. After the RAD expires, the node rebroadcasts the message only if the minimal distance is larger than a pre-defined threshold value. Otherwise, the node drops the message since it is very close to some neighboring node that has already broadcasted the message.

For each node of the location-based schemes, it estimates the additional area covered by each forwarding node more precisely [5] with the location information obtained from the global positioning system (GPS) or other similar systems. When a node sends a new message or rebroadcasts the received message, it advertises its location information in the message.

On receiving a new non-duplicate message, each node calculates its distance to the sending node. If the estimated distance is larger than a pre-defined threshold value, the node schedules a RAD and keeps receiving duplicate messages. Once the node receives a duplicate message during the RAD, it checks if the estimated distance to the sending node is sufficient to cover it. If not, the node cancels the RAD and drops the message. Otherwise, it broadcasts the message after the RAD expires.

D. *Neighbor Knowledge Methods*

Each node of neighbor knowledge methods utilizes neighbor information to ensure that rebroadcasting of a message can cover additional nodes. Depending on the number of neighboring hops, 1-hop neighbor schemes and 2-hop or more neighbor schemes [8] are two typical neighbor knowledge methods. For a node to obtain its neighbor information, each node periodically broadcasts a hello message with its identity. On receiving a hello message, a node obtains the identity from the message and adds it to its neighbor list. For 2-hop neighbor schemes, the broadcasted hello message also includes 1-hop neighbor information of the sender.

Flooding with self-pruning (SP) [9], [10] is a simple 1-hop neighbor scheme whose node periodically broadcasts a message associated with its neighbor information to neighboring nodes. On first receiving a new message, each node compares its neighbors with the neighbor information of the received message. If there are additional nodes not included in the message, the node broadcasts the message with its neighbor information.

Since each sender of a message is a neighbor of its receivers, a receiver can utilize their 2-hop neighbor information to figure out if a message sent by the sender already covers its neighbors. The scalable broadcast algorithm (SBA) [11] is a simple method that examines 2-hop neighbor information. For a node receives a message for the first time, it checks if all its neighbors are covered by the sender. If not, the node schedules a RAD and keeps receiving duplicate messages during the RAD. On receiving a duplicate message, the node continues checking the neighbor information of the message. If the received, duplicate messages have already covered all neighbors of a node, the node cancels the RAD and drops the message. Otherwise, after the RAD expires, the node immediately rebroadcasts the message.

III. Node-Stamping Approaches

In dense networks, it is helpful to drop some broadcasted messages to reduce duplicate messages without affecting coverage; since each node has many neighbors in dense networks, a node is likely to receive the same message many times from its neighboring nodes even if some nodes randomly drop the duplicate messages. For probability-based methods, nodes in dense networks try to stop forwarding the received messages that other nodes might have already rebroadcasted. In sparse networks, however, the node forwards almost every messages it received because there is only little chance for a node to be covered by many other nodes.

The accuracy of neighbor information and the RAD for the neighbor knowledge methods affect redundancy check dramatically. In addition, the node may broadcast some duplicate messages along the disjoint paths whose nodes have no neighbor information about each other. 2-hop neighbor information of mobile ad hoc networks is also changed very often and less reliable. To maintain timely neighbor information, it will cost higher to exchange more hello messages.

To ensure the accuracy of neighbor information, we propose node-stamping approaches in which each node appends its identity or up-to-date neighbor information as stamps to the message. On receiving a message, a node uses these stamps to determine whether to broadcast it. If the node decides to broadcast the message, it adds its identity and up-to-date neighbor information to the message's stamp list to denote that it has ever received the message [12].

```
Basic Stamping
if m is not a duplicate message then
  for each node n in N(r) do
    if n is not in the stamp of m then
      r appends id(r) to the stamp of m
      r rebroadcasts m
      exit
```

Fig. 1. Basic stamping algorithm.

```
Advanced Stamping
if m is not a duplicate message then
  for each node n in N(r) do
    if n is not in the stamp of m then
      r appends id(r) and id(N(r)) to the stamp of m
      r rebroadcasts m
      exit
```

Fig. 2. Advanced stamping algorithm.

The denotations used in the proposed node-stamping algorithms are described as follows. Each node *v* in the node set *V* of a network has its own unique identity, denoted as *id*(*v*). All nodes have the same transmission range *R* and the nodes in the transmission range of node *v* are neighbors of *v*, denoted by *N*(*v*). The sender can periodically advocate its identity and its neighbor information in the hello messages or in the broadcasted message *m*.

A. Basic Stamping

Basic stamping is a 1-hop neighbor scheme of the neighbor knowledge methods, in which each node *r* appends its identity *id*(*r*) directly to the stamp list of a message *m*. As shown in Fig. 1, when node *r* receives a broadcast message *m*, it checks whether message *m* is a duplicate message or not. If message *m* is a new message, node *r* checks if the stamp list of message *m* covers all its neighbors *N*(*r*). If there are uncovered neighbors, node *r* appends *id*(*r*) to the stamp list of message *m* and broadcasts it. Otherwise, node *r* drops the message.

Conventional 1-hop neighbor schemes use the neighbor information of the last sending node only. By appending the new node to the existing list, the stamp list accumulates *id*(*r*) of all nodes along the path from the source node to the receiving node. On receiving a new message, the node can stop to broadcast the message if all its neighbors are already included in the stamp list. To improve basic stamping further, the node can also adopt the RAD as well to increase the chance to reduce redundant messages further if node *r* receives duplicate messages from other neighbor nodes along different paths before the RAD expires.

B. Advanced Stamping

Advanced stamping is also a kind of 1-hop neighbor scheme of the neighbor knowledge methods, but in addition to its identity *id*(*r*), each node *r* appends its neighbors *N*(*r*) to the stamp list of a message *m* in advance. As node *r* broadcast message *m*, all neighbor nodes *N*(*r*) are supposed to receive message *m*. Thus, the node can append their identities to the stamp list in advance to indicate the covered nodes accurate and fast.

Fig. 2 shows the pruning process of advanced stamping. When node *r* receives a broadcast message *m* for the first time, it checks the stamp list of message *m* whether all its neighbors *N*(*r*) are already covered. If so, there is no need to rebroadcast the message because it does not make additional coverage; otherwise, node *r* appends *id*(*r*) and neighbors *N*(*r*) to the stamp list and schedules for rebroadcasting.

Since the broadcasted message of the advanced stamping scheme always has the up-to-date 1-hop neighbors of a node, it is not necessary to advertise the hello message with 1-hop neighbor information. If there is no change of neighbors within a certain time, the list may have a pointer to reuse existing *N*(*v*) without the need to append *N*(*v*) in every message.

C. Hybrid Stamping

In the basic stamping scheme, the stamp list keeps track of the up-to-the-minute nodes visited along the traveling path of the message. In the advanced stamping scheme, the stamp list further keeps track of each visited node's neighbors. Both schemes use only 1-hop neighbor information. Compared to basic stamping, advanced stamping can prevent the neighbors *N*(*r*) of node *r* from broadcasting the same message to each other. However, it is possible that these neighbors *N*(*r*) share some common neighbors not presented in the stamp list

The hybrid-stamping scheme utilizes 2-hop neighbor information further for pruning. In hybrid stamping, each node collects the 2-hop neighbor information like conventional 2-hop neighbor schemes from the hello messages advertised by its neighbors with their 1-hop neighbor information. Each node further checks whether any node of the stamp list can also reach its neighbors. If so, the node decides whether to forward for these neighbors. In the current proposal, the node that has the identity of lowest alphabetic order is responsible to broadcast the message to the node that is covered by more than one node.

```
Hybrid Stamping
if m is not a duplicate message then
  for each node n in N(r) do
    if n is not in the stamp of m then
      for each node p in N(n) do
        if p is in the stamp of m and
          p has a higher priority than r then
          break
        r appends id(r) and id(N(r)) to the stamp of m
        r rebroadcasts m
        exit
```

Fig. 3. Hybrid-stamping algorithm.

As show in Fig. 3, when node *r* receives a new message *m*, it first checks if its neighbors *N*(*r*) are all included in the stamp list of message *m*. For each neighbor *n* not included in the stamp list, node *r* then tries to check if there is a neighbor *p* in *N*(*n*) is in the stamp list. If node *p* has higher priority than node *r*, node *r* assumes that node *p* or other node will cover node *n* with higher priority.

IV. Stamp Reduction and Compression

With tracking of visited nodes and detecting of common neighbor nodes, node-stamping approaches are promising to improve broadcast efficiency by reducing redundant messages in wireless ad hoc networks. However, as a message travels more hops of nodes, the stamp list of the message also accumulates more stamps of visited and neighbor nodes. This would increase the size of the message as well.

To improve the performance of node stamping further, we examine two schemes to reduce stamps without decreasing broadcast efficiency. The first scheme is to reduce the number of stamps by limiting the number of levels or the number of stamps to be included in the stamp list. It works like a sliding window of only nearest visited nodes or neighbors for a message. The other scheme is to reduce the size of a stamp by compressing.

A. Stamp Reduction

Along the traveling path of the message, the stamp list in basic stamping keeps track of the visited nodes, and the stamp lists of advanced stamping and hybrid stamping keep track of the visited nodes and their neighbors. Considering a path of n nodes with N neighbors per node in average, the length of the stamp list in basic stamping is n and the lengths in the other two stamping approaches are less than $n*N$. Since two closer nodes have higher probability to have common neighbors, far-away nodes or neighbors may have little help for preventing redundant broadcasting.

Depending on the size of the network and the constraint of the stamp list, we may slide a window to track only the nearest visited and neighbor nodes in the stamp list. There are two possible designs for the sliding window: the first design is to track the nodes only up to a certain hop or level away, and the other one is to maintain a maximum number of stamps to be included in the stamp list.

For reduction by limiting stamp levels, the stamps of the present node and its neighbors replace the stamps of the farthest visited node and its neighbors in the stamp list. For reduction by limiting the maximum number of stamps, the newest stamps of the present node and its neighbors replace the oldest stamps instead. Note that advanced stamping with the limit of one level performs the same as the 1-hop neighbor scheme; the node of both schemes advertises its neighbor information in the broadcasted message.

B. Stamp Compression

Stamp reduction may reduce the number of stamps to be included in the stamp list, but it may not be effective for a small-size network or a large-window stamp list. In these cases, all stamps accumulated along the path are possible to be included in the stamp list up to the final nodes since there are few nodes to be included in the stamp list or there are many spaces to include all stamps, respectively.

In addition to stamp reduction, stamp compression can reduce the cost of the stamp list by decreasing the message size for the stamp list. We may reduce the space of a stamp to its minimum for representing an identity. For a network with N nodes, each stamp requires about $\lceil \log_2 N \rceil$ bits for the identity space {0, …, N-1}. For nodes with non-contiguous identities, it may require more bits for each stamp. In this case, hash functions would be useful to shorten the size of a stamp. In our simulation, we demonstrate the case that hashes a 4-byte IPv4 address into a 1-byte integer. Certainly, there would be collision for the hashed values in a large network, but it may be tolerable for a network with medium size.

V. Evaluation

To analyze the performance of the proposed node-stamping algorithms, we compare them with three other well-known algorithms: blind flooding (BF), self-pruning (SP) and scalable broadcast algorithm (SBA). Table I shows the default simulation parameters. For each experiment, we randomly pick a node as the source node of broadcasting.

TABLE I: Simulation Parameters

Parameter	Value
Simulator	ns-2
MAC Layer Protocol	MAC 802.11
Bandwidth	1 Mb/s
Transmission Range	250 m
Data Size	64 bytes
Number of Nodes	64, 128, 256, 512 and 1024
Network Size	1,000,000 m^2
Number of Trials	20

A. Stamping without Reduction and Compression

Fig. 4 shows the ratios of forwarding nodes for different algorithms with various numbers of nodes in the network. To simplify the analysis, the protocol overhead of each algorithm is not considered. The results show that all the stamping algorithms perform better, and hybrid stamping significantly outperforms the others on reducing the number of forwarding nodes. As the number of nodes increases, the network become denser. However, the ratio of forwarding nodes for hybrid stamping superisingly decreases; it performs much better than the others.

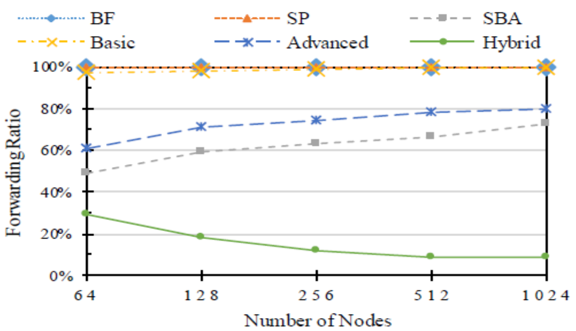

Fig. 4. Comparison of broadcast efficiency.

Without using RAD, a node of basic stamping drops a message only if all its neighbors have sent the same message to it; it has very limited improvement on reducing the number of forwarding nodes. Since SBA adopts RAD, it gets more chances to detect more redundant messages than advanced stamping. Since hybrid stamping utilizes the stamp list and 2-hop neighbor information to check redundant transmissions, it is likely their neighbors may be reached by each other when considering the transmission range. The results show that hybrid stamping achieves more improvement when the number of nodes grows since it can prune more unnecessary transmission with more neighbor information.

B. Reduction by Limiting the Stamp Level

In this simulation, we reduce the stamp list to include only the visited nodes and its neighbors within a specific number of hops. The network size is 1,000,000 square meters and the transmission range of each node is set to 100 meters. There are 1,000 nodes randomly distributed within the network.

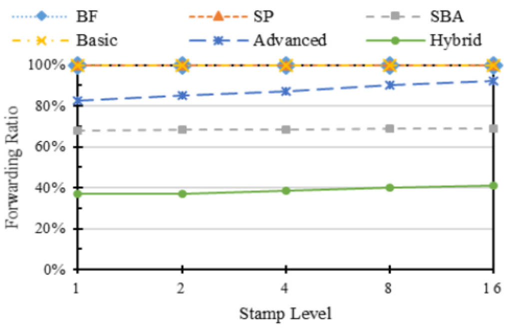

Fig. 5. Effects of limiting the stamp level.

Table II and Fig. 5 show the simulation results. Since the stamp level has not effects on the algorithms other than stamping schemes, we include them for comparison. Considering the delivery ratios, all stamping schemes with different stamp levels can reach delivery ratio of 100%. These may indicate that the simulated networks are dense and each node could be covered many neighbor nodes.

TABLE II: DELIVERY RATIO

Level	1	2	4	8	16
BF			100%		
SP			100%		
SBA			100%		
Basic	100%	100%	100%	100%	100%
Advanced	100%	100%	100%	100%	100%
Hybrid	100%	100%	100%	100%	100%

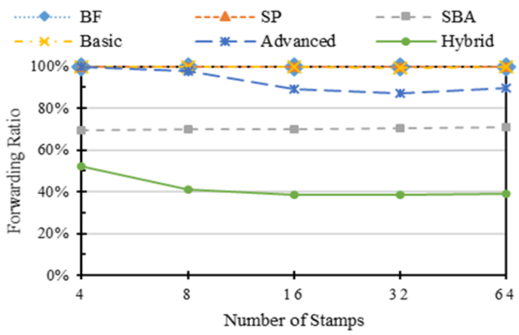

Fig. 6. Effects of limiting the maximum number of stamps.

As the results suggest, the stamp level has no significantly effects on the ratios of forwarding nodes in advanced stamping and hybrid stamping. This indicates that in the simulation settings one-hop neighbor information is sufficient for stamping to prune unnecessary retransmission. As the level increases, it will take longer time to broadcast a message. This incurs the penalty that it increases the transmission time of the message and raises the possibility of signal collision.

C. Reduction by Limiting the Number of Stamps

In this experiment, the maximum number of stamps to be included in the stamp list is limited to 4, 8, 16, 32 and 64, respectively. The newest stamps of the present node and its neighbors replace the oldest stamps in the list. Since all the delivery ratios are also 100%, we skip the results. As shown in Fig. 6, the ratio of forwarding nodes in hybrid stamping decreases as the maximum number of stamps increases. Since the average node degree in the network is 31, the number of stamps should be larger enough to include 1-hop neighbors. If the maximum number of stamps is less than the number of neighbors, it may not be able to prevent broadcasting a message to the neighbors that have already receives the message.

D. Compression by Hashing

Node stamping improves the broadcast performance by reducing redundant messages, but the size of a message increases as it travels more hops of nodes to carry more stamps along the traveling path. Therefore, the transmission time of the message and the possibility on causing signal collision both increase. In this simulation, we compress each stamp from 4 bytes to 1 byte by hashing.

Fig. 7 shows the results of uncompressed stamping, and Fig. 8 shows the results of compression by hashing. When the transmission range of each node is small, the stamping overhead is relatively high. As the transmission range increases, a node can prune more nodes. The performance improvement of hybrid stamping with compression is about 20% better than the original one.

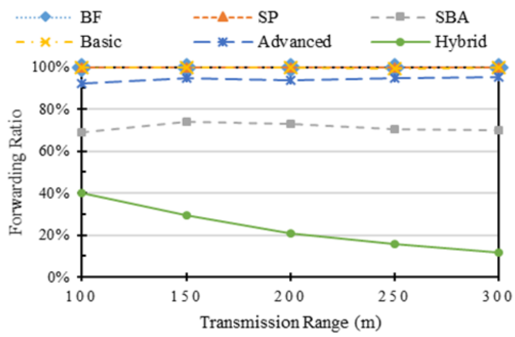

Fig. 7. Effects of transmission range without compression.

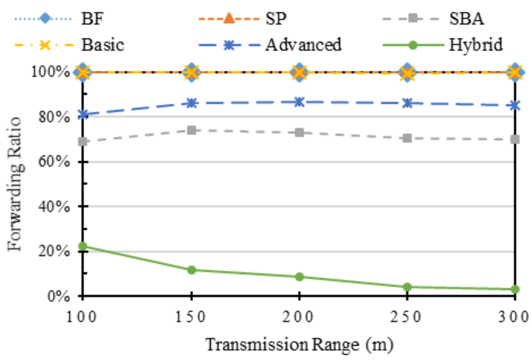

Fig. 8. Effects of stamp compression.

VI. Conclusion

We propose node-stamping approaches to efficient message broadcasting for wireless ad hoc networks by tracking the visited nodes and up-to-date neighbor information in the stamp list of a message. With different node-stamping and redundancy-pruning schemes, the proposed node-stamping schemes lead to different levels of performance improvement. The simulation results show that hybrid stamping significantly outperforms the others, and the performance improvement of hybrid stamping gets better as the average node degree of the network increases. The proposed stamp reduction and compression techniques effectively reduce stamping overhead while maintaining reasonable delivery ratios. The enhanced node-stamping approaches can attain high broadcast efficiency with lower stamping costs for wireless ad hoc networks.

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Chun-Hsin Wu received his B.S. and Ph.D. degrees in computer science and information engineering from the National Taiwan University, Taiwan, in 1992 and 1999, respectively. He is presently an associate professor of the Department of Computer Science and Information Engineering, National University of Kaohsiung, Taiwan. His research interests include wireless communication, mobile networks, computer networks, distributed systems, and ICT systems.

Chia-Wei Li received his B.S. and master degrees in computer science and information engineering from the National University of Kaohsiung, Taiwan, in 2008 and 2011, respectively. He is presently a senior freelance software developer. His research interests mainly focus on computer networks, social networking, and web development.