VIRTUAL BACKBONE CONTENT ROUTING IN WIRELESS AD-HOC NETWORK

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ABSTRACT

We developed a new content routing based on the virtual backbone structure, which groups wireless nodes and contents into a virtual architecture. Our approach is scalable, works with local information, and does not rely on address information. The naming system uses flat naming to identify nodes and contents, and organizes these identifiers together. Backbone nodes can be selected automatically or pre-defined to direct their associated normal nodes in a local area. The normal nodes are guided by the backbone nodes to full fill the searching and routing processes. With a virtual structure, the searching performance can be improved by using the DHT technique.

Experiments using ns2 simulator demonstrate that this virtual backbone routing architecture has the following significances: workable without being aware address in a mobile situation; scalable with the size of network; efficient in terms of the reduced hop counts and short end-to-end delay, and also resistant to the dead-end problem.

Keywords

Virtual backbone structure, wireless networks, distributed hash table, routing, flat naming

1. INTRODUCTION

The wireless network is promising because it is easy to deploy without requiring centralized management. The content delivery in wireless networks is attractive because the wireless and sensor networks are being integrated into the Internet [1]. More and more traffic today in Internet is the peer-to-peer applications [2] which are content based. It is expected to have a high demand for content delivery in wireless network in near future. To meet this growing trend, the content routing solution has been proposed by using the name-based routing [3]. The proposed network consists of Content Routers (CR) to provide support in the Internet to distribute, maintain and make use of the content delivery; the Name-Based Routing Protocol (NBRP) to distribute the names and set the routing tables to provide routing in a structure similar to BGP; and the Internet Resolution Protocol (INRP) to perform efficient lookup on the distributed integrated name-based routing system. This approach

The naming system is designed to identify a node or content into certain sized digital value. We use the mathematics module to shrink those binary values with different size into certain size unique values, name identifiers, which are used for the searching and routing.

The searching system is designed to find the corresponding destination node or content correctly and quickly. This function is especially important for peer-to-peer application, where most of traffics are content based and distributed among different nodes.

The primary routing schemes currently used in wireless networks are the address routing [4]. These schemes use the geographic address to identify and locate mobile nodes. To support searching and routing packets, the address routing schemes in wireless network need to deploy servers or beacons [5][6] to allocate addresses. But, when we consider the mobility character of wireless network, the address cannot be treated as a unique identification for mobile nodes. And also, the address routing needs a certain identifier to route the packet, such as URL. Thus, the address routing is not suitable for the next generation wireless network. Although, it is possible to build a large address network [7] today, such as Internet with Domain Name Service (DNS) [8] server. It is difficult to implement an address wireless network with mobility, energy-awareness, and self-learning. In order to overcome these drawbacks, we propose a novel name identifier and content routing structure, virtual backbone routing. This routing scheme uses embedded [9] name identifier to route packets without being aware addresses.

In wireless networks, nodes may be mobile and organize themselves into arbitrary configurations. Due to their dynamic nature and resource limitation, routing in wireless networks should be scalable, distributed, localized, and would be ideal if no global servers involved. The tree-based routing structures [11] require re-structuring the global tree structure when a node join or leave the network which happens very often in wireless networks. The address-based routing [5] requires every node knows its own position for making forwarding decision which is not suitable for the content routing because it requires significant overhead to maintain the mapping between the content and its address, especially becomes hard when the node moves around frequently. To improve the routing efficiency, we propose a virtual backbone routing scheme to route packets. The structure can be used to easily manage the network topology when a node joins in or leaves the network. The routing can also takes the advantages of the virtual structure built based on these backbones.

We analyze the virtual backbone content routing scheme, show that it is correct and efficient, and present simulation results to support our analysis by using ns2 [12] simulator.

By analyzing these characters, we believe the content routing should be based on name identifiers rather than addresses. Also using the virtual structure to organize those backbones together can improve the routing efficiently. It should also be scalable in the following senses:

1) The global routing information should be avoided or restricted due to the limited memory of wireless nodes.

2) The flooding or broadcast messages should be avoided or limited in the searching process.

3) The routing process should be smart to take shorter path without going through every node along the route.

4) The dead-end problem should be mitigated to a certain extent.

The rest of the paper describes the design and simulated performance of this virtual backbone routing scheme. Section 2 reviews existing routing schemes in wireless network. Section 3 describes the structure and algorithms of virtual routing scheme in details. Section 4 studies the simulation results. Section 5 suggests areas for future research. Section 6 summarizes the paper's contributions

2. RELATED WORK

There has been a large amount of work on routing protocols for wireless network. Based on their principles and performances, we can classify them into three generations. Each generation has its own characters and contributions.

The first generation of routing schemes for wireless network primarily focuses on data collection. It mainly includes reactive and proactive protocols [13][14]. The proactive protocols, such as Destination Sequenced Distance Vector (DSDV) [14][15] and Optimized Link State Routing protocol (OLSR) [16], need to maintain consistent up-to-date routing information from each node to every other nodes. Reactive protocols, such as Dynamic Source Routing (DSR) [17][18] and Ad-hoc On-demand Distance Vector Routing (AODV) [19][20], construct routes to destinations only when they need. The need is initiated by the source, as the name suggests. When a node requires a route to a destination, it floods a route request message within the network. If a node receives a route request, it responds with a route reply. Unfortunately, this process may lead to significant flooding the network in order to discover the desired route. The first generation wireless network engrosses vast of bandwidth and energy due to the flooding traffic involved. Also it is difficult to be implemented in a large scale network.

The second generation of routing protocol for wireless network is the coordinator-based routing protocol which uses coordinator-based identifier [11][6][5] to locate nodes and perform the searching and routing process. Beacon Vector Routing protocol (BVR) [6] and Greedy Perimeter Stateless Routing (GPSR) [5] belong to this category. These schemes need the global or local coordinators to direct the routing process. The coordinator-based routing protocols are efficient and smart, since they utilize the geographic information to get the accurate address of the destination and use this information to forward packets. However, in order to implement the coordinator-based searching and routing functions, we need to set up the fixed infrastructures for the servers [5] or beacons [6] and maintain them as well. That could be very expensive or impossible in some cases to equip every node with the global server (e.g., Global Positioning System) [5]. Further, these local or global infrastructures need to be updated regularly.

During this time, a new peer-to-peer mapping and searching protocol, Distributed Hash Table (DHT) [21][22][23][24], has been developed. DHT is a building block for peer-to-peer applications. At the basic level, it allows a group of distributed hosts to collectively manage a mapping from keys to data values, without and fixed hierarchy, and with very little human assistance. This building block can then be used to ease the implementation of a diverse variety of peer-to-peer [25][26] applications such as file sharing services [27][28], DNS replacements [29][30] and web caches [31][32]. Although, DHT originally was created and used in wired network, ideas and mechanisms can be applied and implemented in a wireless network.

With the DHT, the third generation of wireless network with name routing becomes true. Each node can use a name as a unique identifier (i.e., MAC address) and distribute it among in a wireless network without pre-defined address information. By using this way, name routing avoids drawbacks of address routing and can be deployed in a large network where each node can identify its name by through self-learning process. Virtual Ring Routing (VRR) [33] is an originator for the name routing. The VRR uses the node's natural identifier and DHT to map nodes into a ring. Based on this ring, VRR performs continuous hash searching and single route routing. This routing protocol can achieve name routing and avoid drawbacks in the address routing. However, the routing performance of VRR is in doubt. It uses clockwise or anti-clockwise to forward Node Hashed Identifier packets, sometimes this single route may be the worst route. And also, the VRR has a high risk to encounter the dead-end problem [34], since the DHT ring is created by continuous hash function and with the order of nodes' hash value. Recently, we developed the virtual backbone routing scheme which belongs to the name routing category, but it improves the routing performance which VRR has suffered from the single level routing. With the associated backbone nodes, normal nodes in this structure can maintain their natural connection relationship and find other nodes' relationships, which can efficiently mitigate the dead-end problem. With the virtual backbone structure, packets do not need to go through every node along the route to the destination. Instead, lots of packets can be forward direct to their destination with the backbone node's director.

The content routing is a natural extension from the name routing. By our knowledge, there is no other work that integrates the name routing and the content delivery in wireless networks so far. However, a name-based content routing protocol in the Internet was outlined by Gritter and Cheriton [3]. They propose a new type of routing Content Routing (CR) that aims to reduce the time needed to access content in the Internet. The main idea is to have a network based scheme for content discovery through content routers. Our work shares a similar spirit with it but differ in how to construct the naming data structure and how to route messages due to the unique characters of wireless networks. Our work, virtual backbone content routing, organize all of backbone nodes into a virtual structure and perform the content searching and routing.

3. BACKBONE SELECTION

There are some challenges to implement the content routing in wireless networks: addresses cannot be used to identify mobile nodes because network topologies are not static; some wireless node has limited resources in terms of memory and power which are sensitive to the size of the routing table; and the routing should be efficient in terms of hops and power.

The virtual backbone routing scheme aims at fixing these problems. First, it gets rid of address altogether. That is, we propose to route directly on the name identifiers of the wireless node. Secondly, with backbone nodes, rest of normal nodes can be associated. Thirdly, normal nodes can use the backup route provided by their associated backbone node to route packets and avoid the dead-end problem in some certain extent. Finally, we can organize those backbone nodes into a virtual structure, such as Cord [35] and Ring [33], and use the Distributed Hash Table (DHT) [21][23] techniques, to perform the exponential searching process.

In order to implement and take advantages of the virtual backbone routing scheme, we developed the following components:

- Backbone Selection
- Naming
- Routing

We explain each component in the following four sub-sections.

3.1. Backbone Selection

The purpose of the backbone selection is to distinguish some important nodes from the normal nodes. The “important" nodes are defined as the nodes which have wide connectivity, more power, and relative immobility. The backbone node is the foundation of this routing scheme. With the backbone node, normal nodes can find the best path to route packet to other nodes which associated with other backbone nodes and use the backup route to mitigate the dead-end problem. Furthermore, those backbone nodes can be organized into a virtual structure and implement the DHT-like searching functions.

In order to select backbone nodes, we mainly have two different ways. One is manual pre-define the backbone node, the other one is use the backbone selection algorithm. In some topology, the network administer can pre-define which node should be treated as the backbone node according different scenarios. For example, in a business organization, they can choose and deploy wireless nodes into different location to cover all signal range and as backbone nodes, which similar to the router.

The backbone selection algorithm is a self-running algorithm, which does not need to set up any infrastructure. Instead, each node runs this algorithm and gets its backbone selection metric value by itself. Only those nodes whose backbone selection metric values are bigger than the threshold can be selected as the backbone node. The backbone selection metric should include the following items:

- Connectivity
- Power
- Immobility

The connectivity metric is a measure of the relationship among neighbours. Let Na denote the neighbours of node a, including the node itself. Depend on different requirements, we can set up different base B. If Na is bigger than the B, then the connectivity metric is set up as 1. Otherwise, the connectivity metric is set up as the value of Na/B, which should be bigger than 0 and smaller than 1.

The power status is a measure of power capability that can support a node to function properly. It is measured dynamically with a value between 0 and 1, with 0.1 being a minimally maintained power threshold and 1 being 100 percent power capability. The power is expressed as a fraction of 1; the higher the value, the more powerful the node has.

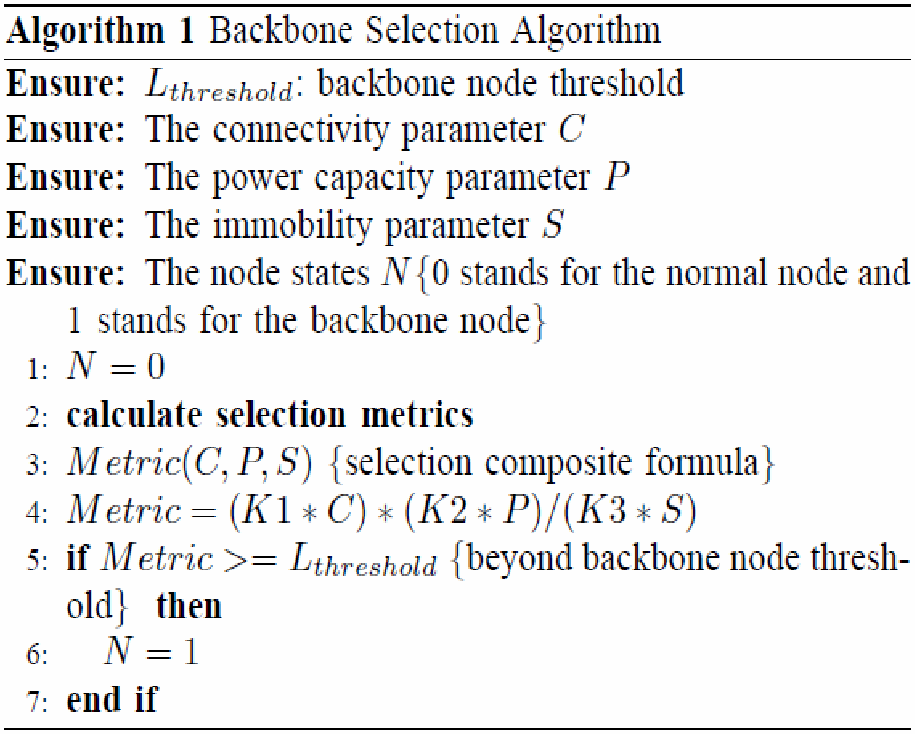
The immobility metric reflects the moving speed of a node and is expressed as a fraction of 100. In this case, a lower immobility value is more desirable because it indicates more stable of the node. So, 1/100 would be a minimally immobile measure, and 100/100 is a node that is 100 percent unstable.

The selection composite formula consists of values K1 through K3, known as the selection metric weights. The connectivity is labelled as C to represent how many one hop neighbours it has and the power is labelled as P to represent the power capacity. The immobility is labelled as S to represent the speed of the mobile node. With these three metrics, we define the selection formula as:

$$\textit{Metric} = (K1 * C) * (K2 * P)/(K3 * S)$$

where the “K" values may be changed according to the real circumstances. By default, K1 is set to 10, K2 and K3 are set to 1. We defined the thresholds for the power and the immobility. When the power capacity is less than the threshold, the weighted factor, K2 is set to a much smaller value, 0.01. The similar processing for the immobility, when a node moving speed is beyond the threshold, the weighted factor, K3 is set to a large value, 100.

The selection process is based on Algorithm 1, which filters and selects backbone nodes from normal nodes. At the beginning, all nodes are treated as normal nodes. Then every node runs the Backbone Selection Algorithm 1 and get the value of node state. With the node statue, nodes with the N=1 can be selected as the backbone nodes.



Algorithm 1 Backbone Selection Algorithm

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Ensure: $L_{threshold}$: backbone node threshold
Ensure: The connectivity parameter $C$
Ensure: The power capacity parameter $P$
Ensure: The immobility parameter $S$
Ensure: The node states $N$ {0 stands for the normal node and 1 stands for the backbone node}
$N = 0$
calculate selection metrics
$Metric(C, P, S)$ {selection composite formula}
$Metric = (K1 * C) * (K2 * P)/(K3 * S)$
if $Metric >= L_{threshold}$ {beyond backbone node threshold} then
    $N = 1$
end if
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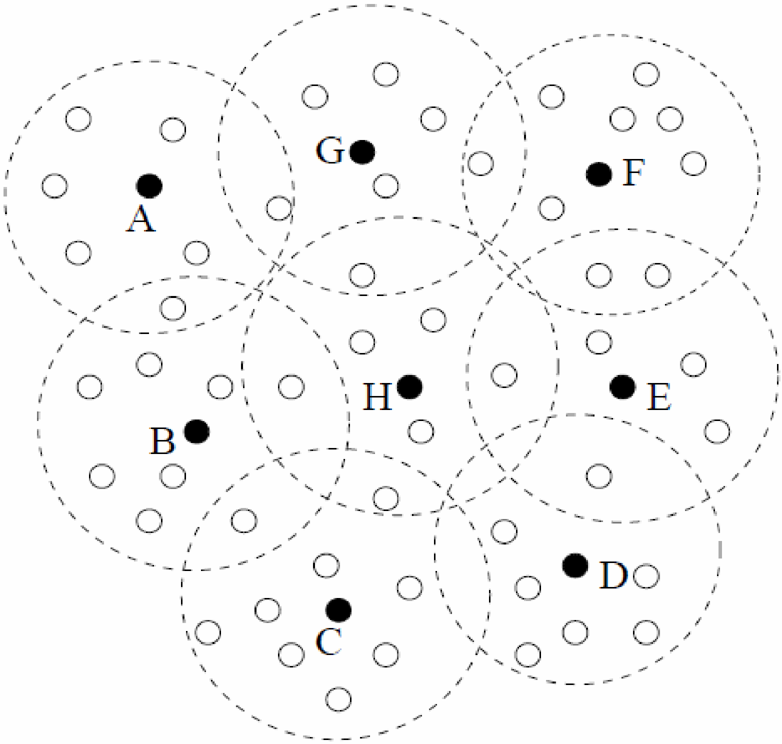
Figure 1. A Sample of wireless Ad-hoc Network

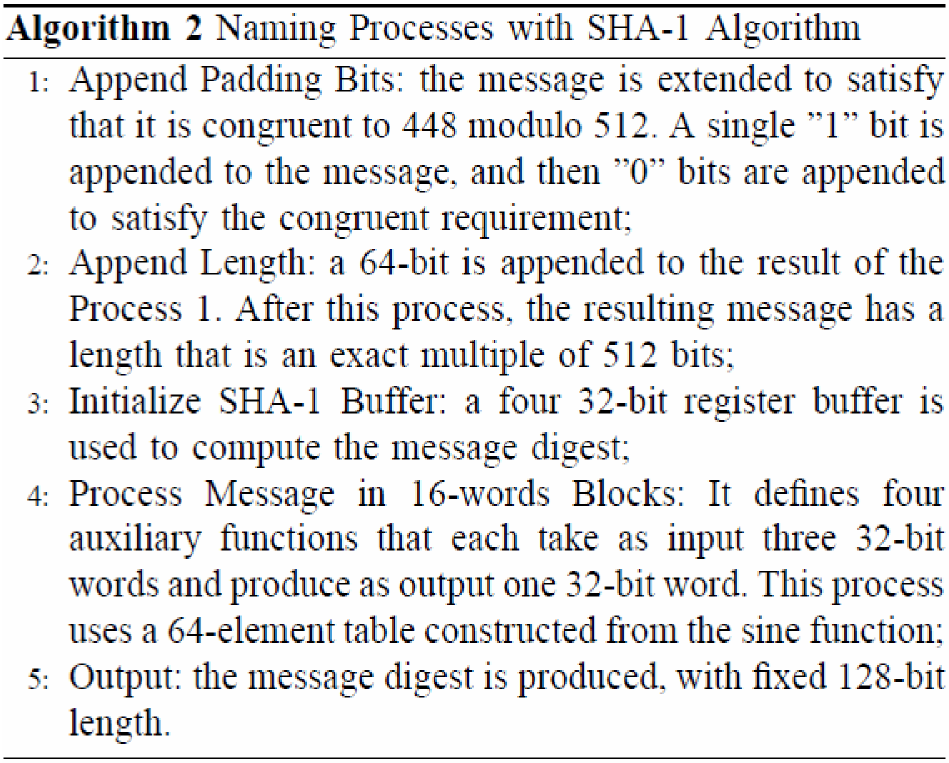


After the backbone selection process, backbone nodes send a 1 hop broadcast messages to inform those normal nodes who received this message that they can send an associate message to this backbone node. Normal nodes send the Associate Message to the first Hello Message received backbone node and ignore other Associate Messages. Backbone nodes have a set to store those associated normal nodes who reply the Associate Message to the backbone node.

As shown in Figure 1, after the automatic backbone selection process, node A, B, C, D, E, F, G and H are selected as backbone nodes. The signal range of these backbone nodes covers all of nodes in this wireless topology.

3.2. Naming

The naming process is the key part of content routing, which gives contents and nodes unique identifiers in this virtual backbone routing structure. After this process, we get two kinds of identifiers, content identifier and node identifier. The content identifier is got by hash function, such as SHA-1 [36]. In this structure, we use the embedded hash functions *ContentHash(Content),* to generate the contents' identifiers. In the *ContentHash(Content)* function, we assign each content a unique identifier by using SHA-1, which has the same size name space. Since the size of the result from SHA-1 is 128 bits, it's unlikely in most cases to see two entries have the same hash value [36]. After the hashing process, contents have their own unique hash values as their identifiers in the network. For the node identifier, we use the natural identifier, MAC address, for each node. Because the MAC address is unique in worldwide and has the same size naming space.



Algorithm 2 Naming Processes with SHA-1 Algorithm

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1: Append Padding Bits: the message is extended to satisfy that it is congruent to 448 modulo 512. A single ”1” bit is appended to the message, and then ”0” bits are appended to satisfy the congruent requirement;
2: Append Length: a 64-bit is appended to the result of the Process 1. After this process, the resulting message has a length that is an exact multiple of 512 bits;
3: Initialize SHA-1 Buffer: a four 32-bit register buffer is used to compute the message digest;
4: Process Message in 16-words Blocks: It defines four auxiliary functions that each take as input three 32-bit words and produce as output one 32-bit word. This process uses a 64-element table constructed from the sine function;
5: Output: the message digest is produced, with fixed 128-bit length.
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For example, assume there are three pictures, Pa, Pb and Pc, are stored at node A. Each picture has different size and the Pa, Pb and Pc are stored as the digital binary format. During the naming process, node A uses *ContentHash()* function to hash these pictures and gets three 128 bit different hash values, *ContentHash(Pa), ContentHash(Pb),* and *ContentHash(Pc).*

3.3. Routing

The routing process takes the advantage of virtual backbone structure. The virtual backbone structure maps all backbone nodes into a virtual structure. One classical architecture is the virtual ring routing [33]. Our structure borrows some technique methods from VRR and extend with our own idea. In our routing scheme, we only put backbone nodes into the virtual structure instead of put all of nodes into it, which is different from the virtual ring routing and the virtual cord protocol. One advantage of this routing scheme is that normal nodes can directly route packets to those nodes that have the same associated backbone node with at most two hops. Another advantage is that it can mitigate the dead-end problem. When the normal node route packets, the associated backbone can choose the best path and keep other paths as the backup. If the backbone node is moved, a new backbone node is selected to take its responsibility. In most of cases, using those back up paths can improve the reliability of the network structure.

In order to set up a routing table, normal nodes send their name identifier and content identifiers to their associated backbone node and are stored in the Content Identifier Storage Table. During this process another two tables are built up for each backbone node, the DHT look-up table and the local index table. The DHT look-up table is used to find the location of target content's visual associated backbone node. The local index table is created to map the certain number of contents to their real backbone nodes. We use the following example to explain our basic ideas. Assume, after the backbone selection process, 8 normal nodes are selected as backbone nodes and all content identifiers are sent to their associated backbone node, from A to H, as Table I. Each backbone node has different number of contents, as shown in this table. Totally, it has 32 contents (We assume the content ID is from 1 to 240).

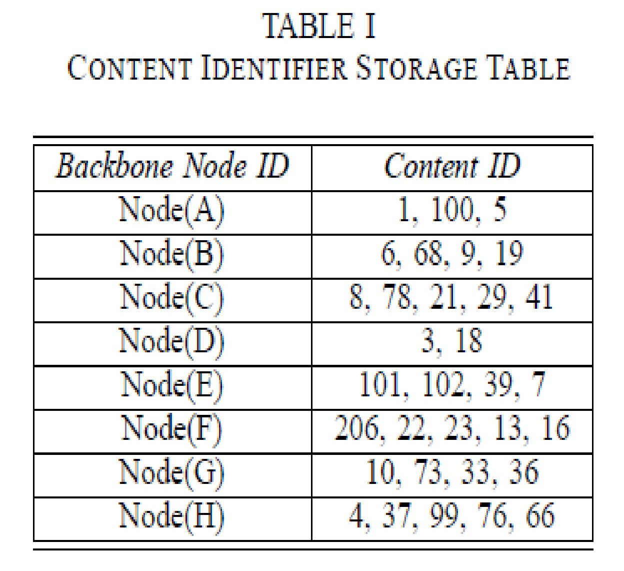


TABLE I
CONTENT IDENTIFIER STORAGE TABLE

Backbone Node ID	*Content ID*
Node(A)	1, 100, 5
Node(B)	6, 68, 9, 19
Node(C)	8, 78, 21, 29, 41
Node(D)	3, 18
Node(E)	101, 102, 39, 7
Node(F)	206, 22, 23, 13, 16
Node(G)	10, 73, 33, 36
Node(H)	4, 37, 99, 76, 66

The DHT look-up table is built with two columns. The first column is the backbone node ID. The second column is the interval of content IDs, which may from different backbone nodes. There are logN (N stands for the number of backbone node) entries in this table and ordered according the DHT theory [21][23]. For the backbone node A, the first column is B, C and E.

The second column is the content ID interval, which is different from the DHT interval. Instead, this interval is used to identify the virtual backbone node which stores the corresponding local index table to identify the real backbone node where the target content can be found. The interval for the first node is C/N, where the C stands for the number of contents and the N stands for the number of nodes. The second interval is 2 * (C/N). The last interval is the rest of content IDs, as Table II.

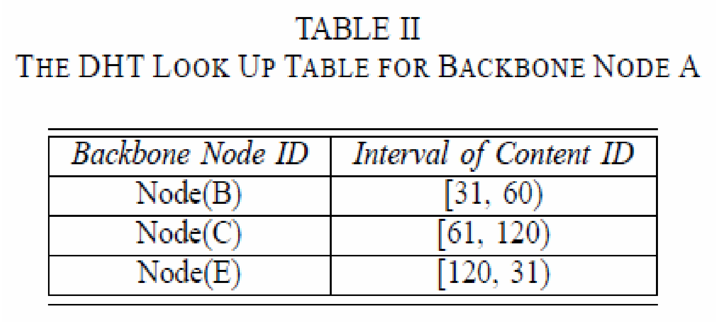


TABLE II
THE DHT LOOK UP TABLE FOR BACKBONE NODE A

Backbone Node ID	*Interval of Content ID*
Node(B)	[31, 60)
Node(C)	[61, 120)
Node(E)	[120, 31)

Since, only the DHT look up table cannot locate the real location for a certain content ID, we nest a local index table to find the real backbone node. This local index table has two columns, Content ID and its relevant Backbone Node ID. Each backbone node store C/N entries, where the C stands for the number of contents and the N stands for the number of backbone nodes in this network. Each entry includes the content ID and its associated backbone node ID. For the backbone node A, it stores the first 4 entries (32 contents divided by 8 nodes), as Table III.

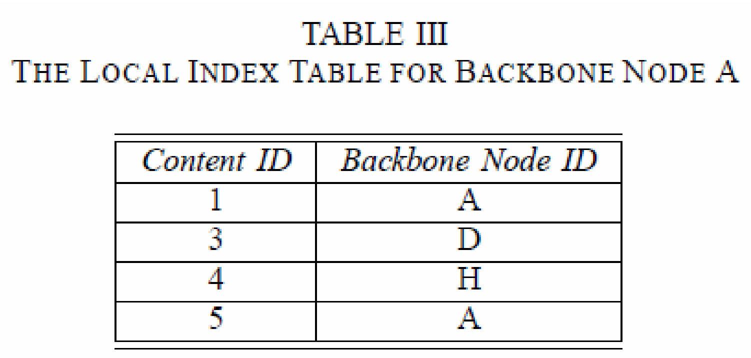


TABLE III
THE LOCAL INDEX TABLE FOR BACKBONE NODE A

Content ID	*Backbone Node ID*
1	A
3	D
4	H
5	A

After this process, a smart and scalable content ID locate and route mechanism is set up. During the searching process, source node can use this two tables with target content ID to find the relevant backbine node ID and in order to forward this packet to the normal node (the destination node).

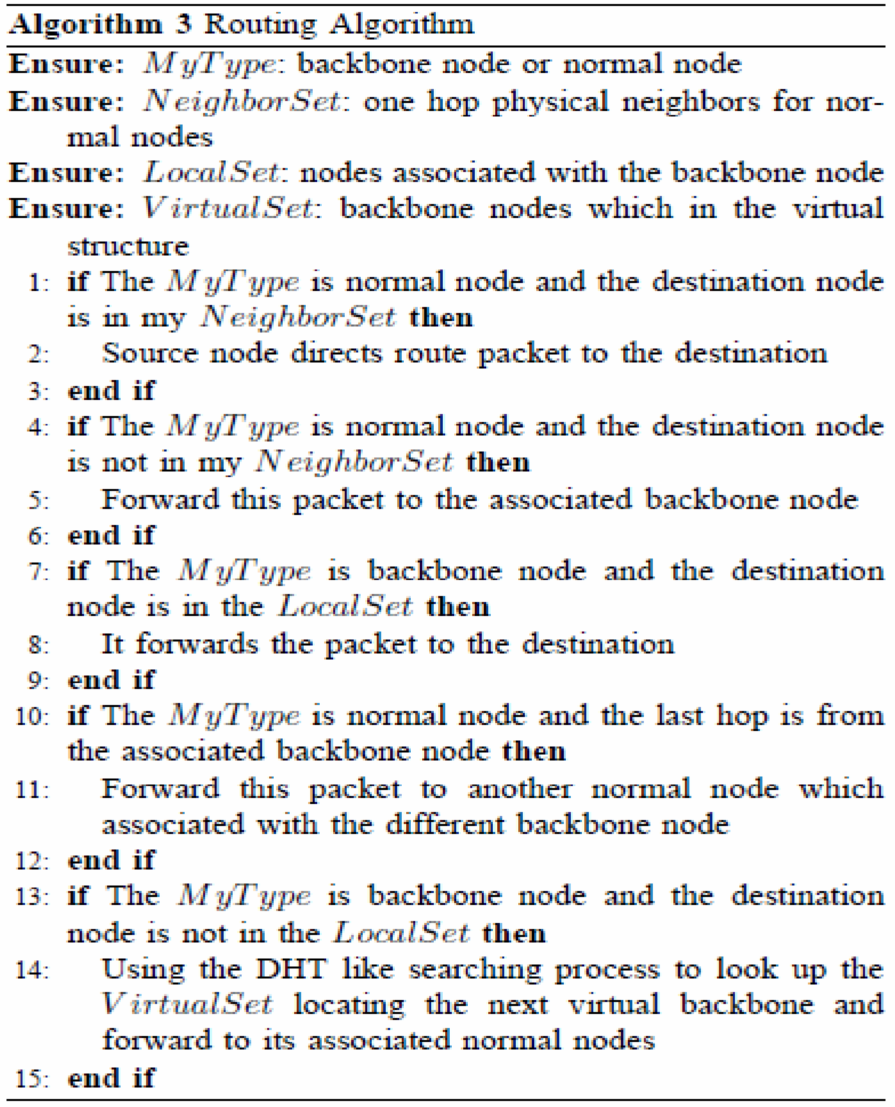
The searching process in the virtual backbone routing architecture is inspired from the Chord [21][37], but we extend it to suit our routing tables. A node in Chord needs only a small amount of “routing" information about other nodes' or contents' identifiers. Since this information is distributed, a node needs only look up O(log N) messages in a N-node network.

At the beginning, if the source node is the normal node, it sends the query to its associated backbone node. When backbone node uses the target content ID to find the destination nodes’ associated backbone, it uses its own DHT look-up table to find the visual backbone node which store the corresponding local index table then using this table to determine the real backbone node which store the target content. Secondly, the backbone node forwards this information to the normal node which sends query to the backbone node. Otherwise, if the source node is the backbone itself, it just directly communicates with the target destination node.

3.4. Scalability

One of the concerns for a routing mechanism is how to make it scalable for a large network. Future wireless network [38] should be a network where a node can join and leave easily without affecting the structure and the connections with other nodes.

The virtual backbone routing scheme performs well in terms of scalability. For normal nodes, they can easily join into a network by find an associated backbone node. When they want to leave the network, they only need to inform its associated backbone node and leave. For backbone nodes, from backbone node selection critical, we use the relative reliably nodes. If it does need to leave, we can use the backbone selection algorithm to select a new backbone node to instead of the original one automatically.



Algorithm 3 Routing Algorithm

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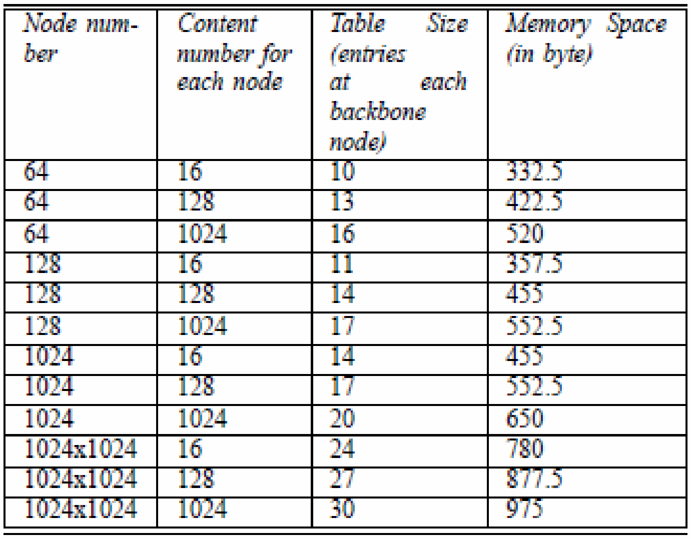
Ensure: $MyType$: backbone node or normal node
Ensure: $NeighborSet$: one hop physical neighbors for normal nodes
Ensure: $LocalSet$: nodes associated with the backbone node
Ensure: $VirtualSet$: backbone nodes which in the virtual structure
if The $MyType$ is normal node and the destination node is in my $NeighborSet$ then
    Source node directs route packet to the destination
end if
if The $MyType$ is normal node and the destination node is not in my $NeighborSet$ then
    Forward this packet to the associated backbone node
end if
if The $MyType$ is backbone node and the destination node is in the $LocalSet$ then
    It forwards the packet to the destination
end if
if The $MyType$ is normal node and the last hop is from the associated backbone node then
    Forward this packet to another normal node which associated with the different backbone node
end if
if The $MyType$ is backbone node and the destination node is not in the $LocalSet$ then
    Using the DHT like searching process to look up the $VirtualSet$ locating the next virtual backbone and forward to its associated normal nodes
end if
```

For the size of routing table in the backbone node, as shown in Table IV, the difference between a small network (less than 1000 nodes) and a large network (more than million nodes) is roughly constant. Clearly, we set 10 bits for backbone nodes' identifiers which can express 1024 identifiers and we use SHA-1 function to hash nodes' identification and the content which costs 2 * 128 bits in total. So for each entry, it needs 33.25 bytes in memory. Moreover, the maximum memory required to accommodate a million nodes is about 975 bytes (assume each node has 1024 contents). In reality, even for the sensor node, which is equipped with more than 4K memory [39], has enough memory to store these tables.

Routing based on virtual backbone architecture, needs a mechanism through which a node can acquire the destination backbone node identifier. Through the searching procedure, the source can obtain the destination backbone node identifier in most of times. Because the content information is distributed among the ring [21], this improves the scalability of the system, as local changes only have an effect on local network resources.

TABLE IV
ROUTING TABLE AND MEMORY SIZE FOR EACH BACKBONE NODE



Node number	*Content number for each node*	*Table Size (entries at each backbone node)*	*Memory Space (in byte)*
64	16	10	332.5
64	128	13	422.5
64	1024	16	520
128	16	11	357.5
128	128	14	455
128	1024	17	552.5
1024	16	14	455
1024	128	17	552.5
1024	1024	20	650
1024x1024	16	24	780
1024x1024	128	27	877.5
1024x1024	1024	30	975

4. SIMULATIONS

In this section, we evaluate the performance of this new virtual backbone content routing scheme mentioned in this paper. We compare the performance of our work (named as VBS) with DSR, AODV and the Single-level Virtual Ring (SVR), where the SVR is similar to the VRR [33]. Since the virtual backbone structure is a new content routing architecture for wireless network, we mainly focus on the searching efficiency [40], routing performance, end-to-end delay and the mobility in this paper.

The simulation experiments run on ns-2 simulator [41], using the wireless extensions developed by the CMU [42]. This simulation environment offers high fidelity, as it includes full simulation of the IEEE 802.11 physical and MAC layers. Moreover, by using the same simulation environment and testing code, we ensure our results are comparable to other routing protocols.

4.1. Evaluation Metrics

In order to evaluate its performance, the following aspects have been studied:

1) Searching performance: the number of hops it takes to find the required content.

2) End-to-end delay: the total time it takes from a source node to the destination node.

3) Routing efficiency: in this experiment, we measure the number of hops it in different routing schemes.

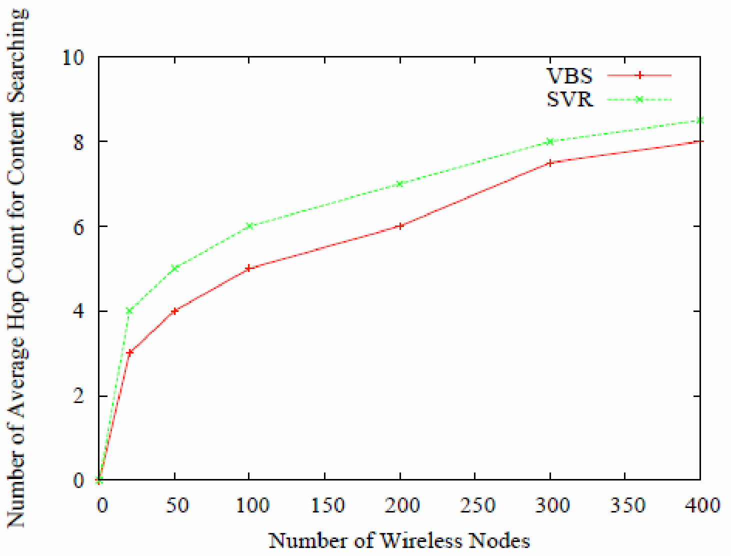
4) Message overhead: this is the total number of control messages generated to exchange and maintain routing schemes.

For each metric, we set up the mobile function, where each node get to a random destination with a random speed. And also, it uses the same traffic and topology patterns for all protocols.

4.2. Performance of Searching Content

One of purposes of this new architecture is to quickly find and locate the content. We use the embedded DHT technique to map all out-of-order contents in to the backbone node and using the virtual architecture to organize these backbone nodes together. In this experiment, we test its performance of searching a content by calculating how many hops are needed to find a certain content in this date management architecture. We compare its searching performance with the SVR. The searching performance has been tested in the different wireless networks which have different number of nodes, range from 50 to 400 respectively. The results are shown in the Figure 2.

Figure 2. Hop Counts to Find Certain Content

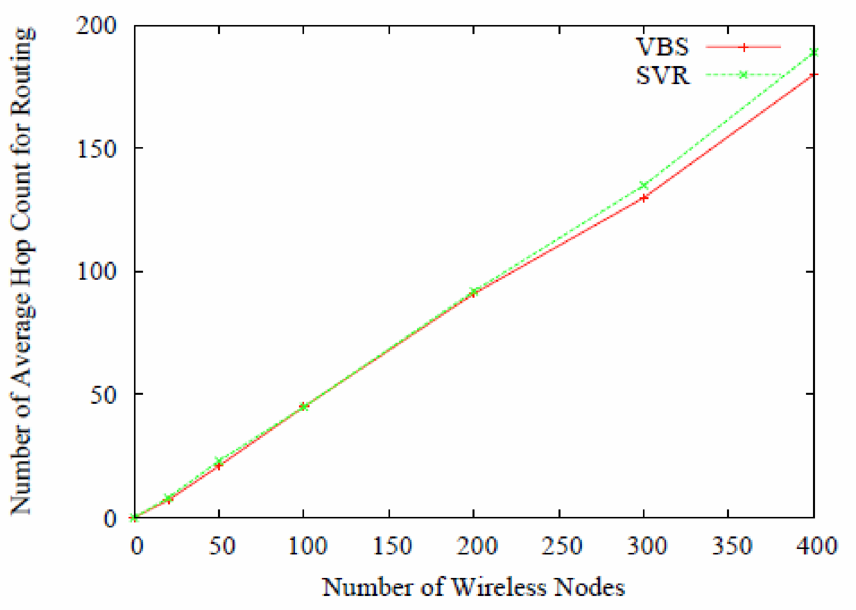


Based on results, we see its searching performance is roughly constant to the size of the network, which indirectly prove the embedded DHT technique is suitable in for our architecture. By analyzing these results, we can find the searching process needs only O(log N) hops, where the N stands for the number of backbone nodes in a wireless network. While in the Single-level Virtual Ring (SVR) structure, the searching process uses the one-way searching, either clockwise or anti-clockwise, thus the performance of SVR is sensitive to the size of the network in which the number of hops required for searching is proportional to the size of the network.

4.3. Performance of Routing Efficiency

Another purpose of our architecture is to quickly route the packet to the right destination. We designed some experiment to test how many hops are needed to route packets by using the virtual backbone routing algorithm and comparing with using the SVR routing algorithm. We have tested wireless networks in different sizes, range from 50 wireless nodes to 400 sensor nodes. The results are shown in the Figure 3.

Figure 3. Routing Performance

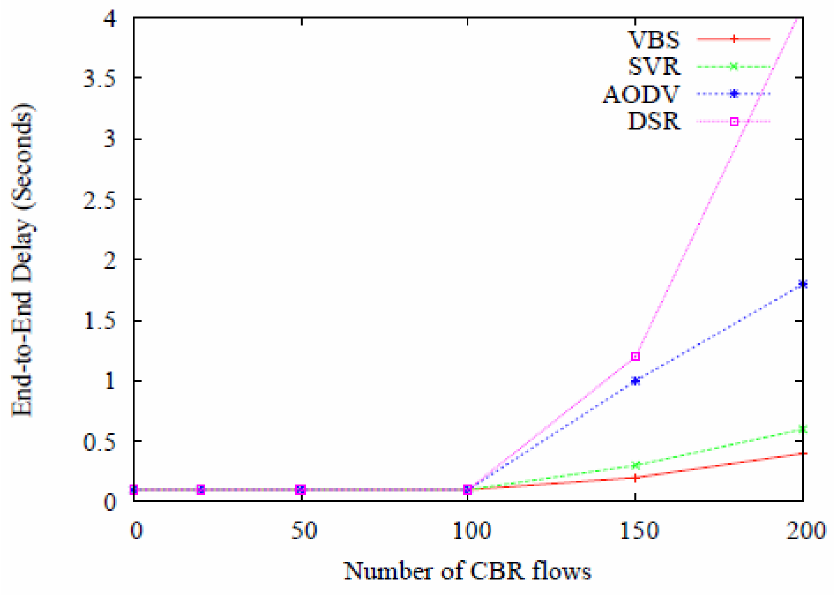


Based on results, we can see our routing performance is slightly better than the SVR. This is because both of these routing schemes include virtual structure and organized by DHT techniques. However, in a small area, our architecture is better than the SVR. Because, we use the backbone node as the co-coordinator in a small area. When the source node and the destination share the same backbone node, the searching and routing path do not need to go through other backbone nodes. Instead, the backbone node can forward the source packet to the destination node directly. This technique is much useful for date management in a local area, such as battlefield.

4.4. Performance of end-to-end delay

The end-to-end delay is an important metric in wireless network. If end-to-end delay is high, this routing protocol is unacceptable. We designed an experiment to test the performance of end-to-end delay. The experiments tested the Constant Bit Rate (CBR) traffic, range from 50 CBR flows to 200 CBR flows. The source node and the destination node are randomly chosen and we measure their average performance.

Figure 4. End-to-End Delay



From the Figure 4, we can see the performances of end-to-end delay for our work, AODV and DSR are similar but for SVR is higher than previous three routing protocols. The reason is that the SVR just maps all nodes' name identifiers to the single ring and applies the one-way route to forward, where it is mapped by the order of nodes' hash value and uses the clockwise to route. Since, this routing protocol is likely to encounter the dead end problem, SVR needs time to process these dead end fallback. Instead, lots of CBR traffic can be routed in the local area with the backbone node as the director, where packets do not need DHT technique to perform outsider searching process. By using this way, packets can bypass some ``useless" node so that the end-to-end delay could be reduced accordingly. This idea is similar to the address routing but we implement it on the content routing structure.

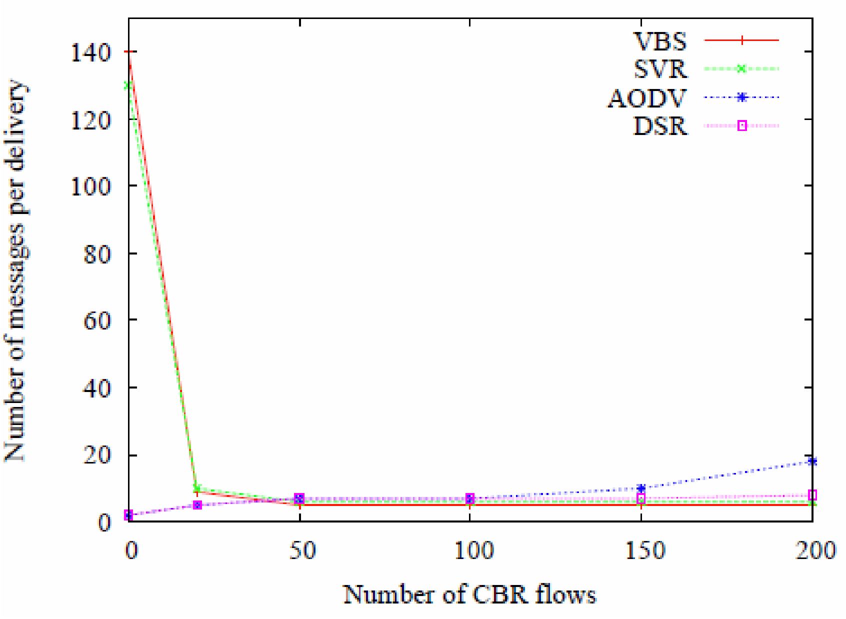
4.5. Message Overhead

To study the efficiency of a routing protocol, we analyzed the message overhead required for our date management architecture. The number of traffic message is the same as before, ranges from 50 to 400.

From the Figure 5, we can see the messages overheads for the AODV and the DSR are quite close, which both start from 0. The results show our work and the SVR need more overhead messages at the beginning. After the virtual structure being built up, our architecture needs the least overhead packets to finish a delivery. However, for the SVR, it needs much more exchanges messages to finish a packet delivery compared with other three routing protocols. This is because the virtual backbone routing architecture needs to run the backbone selection algorithm at the beginning to select backbone nodes. After the backbone selection process, our work needs the least message overhead to route packets, while the SVR uses less message exchanges at the beginning, but it costs more to maintain and repair the dead end problem.

Based on these experiments, we can find that our work is suitable for a large heavy wireless ad-hoc network.

Figure 5. Message Overhead



5. FUTURE WORK

Our work is a new virtual content routing in wireless ad-hoc network. It overcomes the drawbacks of address routing and improves the routing performance of the VRR name routing. With the natural advantages of the backbone co-coordinator, the following area can be extended:

- Virtual backbone architecture can be used in a large wireless network with several backbone domain. In future, every backbone with its associated normal nodes can be treated as a domain, which is similar to the local area network (LAN) structure in wired network. The backbone node is the interface in its own domain and organizes other normal nodes work together to perform the network address translation (NAT) function. This is because, the backbone node stores other normal nodes' information. So, they can be used to implement NAT function to translate nodes' name from inside to outside and from outside to inside as well.

- This virtual backbone architecture can also carry out the grid computing and cloud computing. With the natural characters of backbone architecture, data can be easily distributed [10] among the backbone domain to achieve the load balancing. When it needs to process complex computing, nodes who associated with the backbone node can be organized as a single processing point. Complex data or function can be divided into multiple small data units and each unit can be distributed to some nodes, which depends on that node's capability. Backbone architecture is natural suitable for data distribution and load balancing. Further, Virtual backbone architecture can be developed as a energy efficient routing protocol.

6. CONCLUSION

We present a new content routing scheme based on the virtual backbone in wireless ad-hoc network. The virtual backbone routing architecture gets rid of addresses in routing, instead it achieves not only the name routing but also the content routing. With the backbone selection and naming, the virtual backbone routing architecture can be built up. With exponential searching algorithm and efficient routing forward, our architecture achieves a good routing performance. The backbone selection algorithm was designed to abstract the physical connections among nodes in which some "important" nodes are selected as the backbone nodes. The embedded DHT techniques are used to distribute the content and node information among backbone nodes to improve the searching performance.

With the simulation results, we prove this new architecture can be implemented by deployed and it is suitable for the next generation wireless network compared with other address routing protocols. However, it still cannot root up the dead end problem and has some concerns (i.e., high overhead at the beginning) worth further investigation in the future research work.

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