# VANETCODE: Network Coding to Enhance Cooperative Downloading in Vehicular Ad-Hoc Networks

Shabbir Ahmed
School of Computer Science and Engineering
The University of New South Wales
Sydney, Australia
shabbira@cse.unsw.edu.au

Salil S. Kanhere
School of Computer Science and Engineering
The University of New South Wales
Sydney, Australia
salilk@cse.unsw.edu.au

## ABSTRACT

Inter-vehicular communication is fast emerging as a popular application for mobile ad-hoc networks. Content distribution in Vehicular Ad-Hoc Networks (VANET) is particularly challenging due to the high mobility, rapidly changing topology and intermittent connectivity observed in these networks. Effective mechanisms are needed to enable rapid sharing of real-time such as traffic warnings and multimedia-rich files. In this paper, we propose a novel network coding based co-operative content distribution scheme called VANETCODE. The randomization introduced by the coding scheme makes distribution efficient. Our scheme also leverages on the broadcast nature of the wireless medium to expedite the dissemination of the encoded blocks amongst the one-hop neighbors and is entirely independent of routing. We have carried out extensive simulations to demonstrate that VANETCODE effectively enhances cooperative content sharing in VANETs without introducing additional overhead.

## Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: [Wireless communication]; C.2.2 [**Network Protocol**]: Routing protocols

## General Terms

Performance, Reliability, Theory

## Keywords

Network Coding, VANET, Vehicular AdHoc Networks

## 1. INTRODUCTION

Inter-vehicle communication (IVC) system is a promising solution for future road communication scenarios. The moving vehicles are expected to organize themselves locally in ad hoc networks (VANET) without any pre-installed infrastructure. Such systems will enable drivers to instantaneously obtain information about hazards and obstacles ahead resulting in improved automotive safety and better traffic flow [12, 17].

In addition, passengers will expect to access the vast content available on Internet sites. Rapid vehicle movement results in frequent disconnections and topology changes in VANETs. Conventional client-server content distribution, which is widely used in the wired Internet will experience severe performance degradation in such an environment. Co-operative content distribution solutions are likely to be more applicable in such environments.

In cooperative content distribution systems, each node shares its content with each other nodes. Several cooperative download schemes such as Gnutella and Bittorrent have become popular for the wired Internet. Cooperative networking is a challenge in VANET because of rapid node movement and intermittent disconnection of the nodes. Due to its high speed, a vehicle usually does not get the complete piece of data (e.g. a file) from a single source. If cooperative downloading is employed, then every vehicle can share their data with each other and every one can be benefited by that. For example, if the traffic condition is to be shared among a group of vehicles heading towards a particular direction, cooperative downloading can significantly speedup the process of dissemination of data [4].

In this paper, we propose a novel content distribution scheme tailored for VANET called VANETCODE, which is based on the concept of network coding [20, 10]. In this scheme, the content is divided into smaller blocks and the nodes linearly encode their constituent blocks. The resultant is then shared amongst the neighboring nodes. In ad-hoc networks, since each node can act as a router, the network coding can be done at the network layer at each node without hampering the upper layer protocols. Our scheme also takes advantage of the broadcast characteristics of the wireless medium to speedily distribute the encoded blocks amongst one-hop neighbors. VANETCODE eliminates the need of peer selection, content selection and neighbor discovery, which take up significant time and resource in other cooperative downloading mechanism proposed for VANETs [4]. We have carried out an extensive simulation study to confirm the efficacy of our approach. Our results indicate that VANETCODE significantly outperforms other cooperative content distribution schemes without introducing additional overhead.

The rest of the paper is organized as follows: Section 2


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provides an overview of related work on network coding and cooperative content distribution. Section 3 describes our approach, VANETCODE, which employs a network coding based cooperative content distribution solution for VANET systems. Section 4 presents simulation results and finally Section 5 concludes the paper.

# 2. BACKGROUND

In this section we provide a brief overview of network coding and related work in co-operative content sharing.

## 2.1 Network Coding

Network coding is an effective way to make optimal use of the available network resources. Ashlswede et al. in [17] have shown that by using network coding in the intermediate nodes, a sender can communicate information to a set of receivers at the broadcast capacity of the network. Li et al. [22] have shown that linear encoding is sufficient for interior nodes. Other researchers [14, 23] also have shown some benefits of network coding over routing. Wireless networks are natural for implementing network coding because the performance of wireless ad hoc routing is poor over unreliable channel. Network coding is less prone to a single point of failure. Widmer and Boudec in [24] use linear network coding in delay-tolerant networks to reduce communication overhead. Some interesting features of network coding, which are particularly suitable for wireless networks are discussed in [8].

A practical application of network coding has been presented in [10] for large scale content sharing in the wired Internet. The authors use random coefficients to encode a data block. When a node forwards a block to another node, it produces a linear combination of all its available blocks. It does so by picking up some random coefficients ($C_i$) and multiplies each element of block ($i$) with $C_i$ and finally adds the result. The forwarding node then needs to transmit the encoded blocks as well as the coefficients used in the encoding process. After getting sufficient number of blocks associated with linearly independent coefficients, a receiving node can decode the blocks.

Many researchers [11, 9] have suggested the use of Erasure Codes (or Forward Error Correction Codes) in order to ensure reliable multicast transmissions. The authors in [13] use Tornado Coding to efficiently transfer bulk data, which is quite similar to the method we have used in the encoding part of our proposed method. However, locating missing data efficiently becomes a challenge in that system.

## 2.2 Cooperative Downloading

Cooperative downloading is an inexpensive and effective alternative to mirror servers and content distribution networks. BitTorrent [6] is one of the most popular cooperative distributed downloading protocols in use today. It is based on the principle of swarming, wherein the desired file is downloaded in parallel from a number of cooperating peers. The parallel download approach employed by BitTorrent enables it to achieve improved performance as compared to other peer-to-peer systems such as KaZaA and Gnutella.

With the recent advances in wireless communication technologies and the large growth in the number of mobile users, content distribution in mobile wireless environments is gaining importance. In recent years, several peer-to-peer systems [18] have been proposed for Mobile Ad Hoc Networks (MANET) . Several routing approaches suitable for peer-to-peer file sharing over MANET have been discussed in [7].

VANET is a special kind of MANET where the path, trajectory and velocity of the nodes are quite deterministic. Besides, the nodes in VANET often cross stationary gateways from which they can transfer data. Also the high speed of the nodes in VANET causes several disconnections and subsequent route breakages, which hinder the operation of peer-to-peer protocols that rely on routing for locating the peers.

For VANETs, where the nodes move at a high speed and topology changes rapidly, vehicles can only download partial data from the gateways before disconnection. Therefore it is ideally suited candidate for cooperative content sharing systems. However, most existing peer-to-peer swarming protocols are designed for fixed topology based networks. Due to the changing topology and high mobility, implementing these schemes in VANETs is very challenging. In particular, devising peer and content selection strategies for sharing is quite complex.

In [4], the authors use a new piece selection strategy and a communication efficient swarming protocol called SPAWN to tackle these problems. The SPAWN protocol uses a gossip mechanism to advertise the piece list each node possesses and takes proximity into account when selecting contents among peers. Moreover, leveraging the broadcast nature of wireless media enables SPAWN to reduce redundant transmissions. However, the peer discovery method which is based on gossip mechanism, incurs packet overhead; and the proximity driven piece selection strategy induces delay which might have negative impact on the performance of a VANET with high speed moving vehicles. Our proposed method completely eliminates the need of effective peer selection, piece selection and neighbor discovery as required by SPAWN.

# 3. VANETCODE: NETWORK CODING IN VEHICULAR ADHOC NETWORKS

Before we explain the operation of our proposed protocol, we first discuss the vehicular communication architecture.

## 3.1 Architecture

We assume that every vehicle is equipped with a wireless device, which allows it to communicate with other vehicles and stationary devices within its communication range. We also assume that stationary gateways are installed along the freeways at regular intervals of about 2-10 miles. Similar architectures have been discussed and evaluated in [19] and [21], where the gateways are expected to be co-located with traffic lights, gas stations and rest areas. The communication between the vehicles and the static gateways can use one of the multitudes of access technologies currently available such as Dedicated Short-Range Communication (DSRC) [1], IEEE 802.11 or the newly emerging 802.16 WiMaX [2] standard. In a typical scenario, a car is expected to be within the communication range of a gateway for a short duration of the order of a minute [19]. Further, the WLAN connectivity with the gateway will be intermittent; usually the vehicles have short periods of connectivity with the gateway with alternate longer periods of non-connectivity. Traditional MANET peer-to-peer protocols do not work effectively when the connectivity is highly intermittent. In our

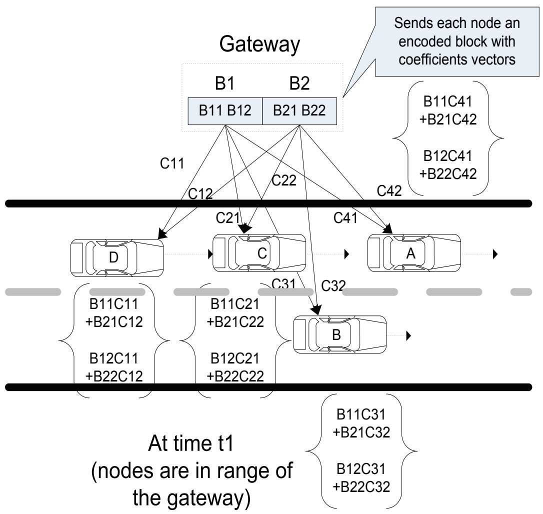


**Figure 1: Encoding and distribution by the gateway**

proposed protocol, during periods of disconnection with the gateways, the vehicles will continue to exchange files in a co-operative manner using network coding, as described below.

## 3.2 VANETCODE

We assume that the files are present in their entirety at the static gateways. These could be proactively distributed by the content providers amongst the gateways, similar to a content distribution network (CDN) or could be downloaded on demand. The gateways, which act as the servers split the original file into $k$ blocks. In SPAWN, these blocks are randomly distributed amongst the different clients and the clients then collaborate with each other to assemble all the $k$ blocks to reconstruct the file. On the contrary, in the proposed VANETCODE protocol, the server produces a linear combination of the $k$ blocks using randomly selected coefficients. The encoding technique that has been used here can be found in details in [10].

In order to explain the operation of our method, a simplified scenario has been illustrated in Fig. 1, where four vehicles ($A$, $B$, $C$ and $D$) pass by a stationary gateway along a freeway. All the four vehicles are within the communication range of the gateway. The gateway has a file to share that has been split into two blocks, $B_1$ and $B_2$, with each block further divided into two elements, $B_{11}$, $B_{12}$ and $B_{21}$, $B_{22}$ respectively. The rationale behind this double decomposition is explained later in this section. Now, assume that all the vehicles request for this file from the gateway.

The gateway then randomly selects coefficients and encodes all the constituent blocks using linear encoding to form a single encoded block. In our scenario, the gateway selects two coefficients $C_{11}$ and $C_{12}$ to encode its blocks. In order to create an encoded block the gateway first combines the first element of both the blocks. For this it multiplies $B_{11}$ with $C_{11}$ and $B_{21}$ with $C_{12}$ and adds the result together to create the first element of the resultant encoded block. Similarly, it encodes the second elements by multiplying $B_{12}$ with $C_{11}$ and $B_{22}$ with $C_{12}$ and adding the result together to get the second element of the encoded block. In other words the

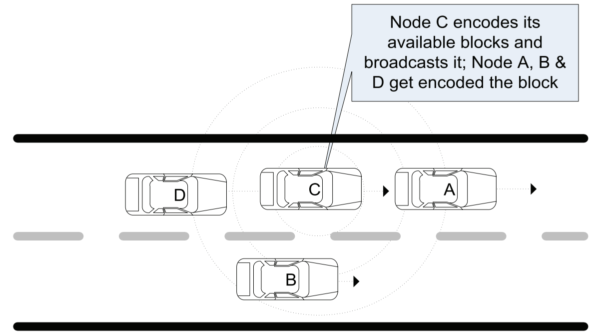


**Figure 2: At time t2, all the vehicles are out of range of the gateway**

following expression will evaluate the $j$-th element of $i$-th block (where $n$ denotes the total number of blocks):

$$\sum_{i=0}^{n} B_{ij} C_i$$

The gateway now sends the encoded block together with the selected coefficient vector ($C_{11}$ and $C_{12}$) to a requesting node. The above operation is repeated for all other requesting nodes, but with different randomly selected coefficients. Fig. 1 shows the encoded blocks received by the four nodes in our example. Note that, all operations have been carried out in finite space. Further, the coefficients are chosen from a very large space of the order of $2^{16}$ [10]. As a result, all the encoded blocks contain information important to all the interested nodes.

Decoding of the data requires the nodes to capture sufficient number of blocks with linearly independent coefficients in order to solve a set of linear equations. The probability that two blocks have linearly dependant coefficients is extremely minuscule since we use random coefficient over a sixteen bit space and also due to the fact that blocks are combined with other blocks as they traverse the network.

A file is split into two levels of hierarchy, with the higher level consisting of blocks and each block further divided into elements to reduce the number of coefficients required for encoding. A simple one level file splitting could be used with the cost of increased coefficient overhead. For example, in the scenario depicted in Fig. 1, the gateway needs only two random coefficients to encode a block. On the contrary, if only one level of hierarchy was used, i.e. the file was split into four blocks then four random coefficients would be required for the encoding process. Note that, the complexity of decoding n blocks by solving linear equations using matrix inversion is $O(n^3)$. Hence, a large number of coefficients will make the decoding process CPU-intensive and time consuming. On the other hand, fewer coefficients and consequently fewer blocks will cause large data chunks, which may not be delivered completely during the small connectivity duration of fast moving vehicles. Hence, it is important to strike a balance between the number of blocks and size of blocks.

Now assume that at time $t_2$, all vehicles are out of range of the gateway, as shown in Fig. 2. Instead of waiting for the next gateway, the vehicles co-operatively share their data blocks amongst each other. However, unlike SPAWN where the nodes need to request for specific blocks that are missing, in our scheme all blocks are linearly independent and hence a node does not need to explicitly request for specific blocks. Each block that a node receives from its neighbors is beneficial. When a node needs to forward a block, it picks random coefficients and linearly combines all the blocks that it currently holds. VANTECODE also takes advantage of the broadcast characteristics of the wireless medium with each node employing a MAC layer broadcast to transmit its encoded blocks. Similar to the gateway, the intermediate nodes also transmit the new coefficients associated with the encoding along with the block. This allows other nodes in its vicinity to passively listen to the broadcast and receive the transmitted block. Similar to the gateways, Fig. 2 illustrates node $C$ broadcasting its encoded block, which in turn is received by nodes $A$, $B$ and $D$.

Simultaneous broadcasts from neighboring nodes will lead to collisions, resulting in loss of encoded blocks. Further, since MAC layer broadcasts are not acknowledged it may not always be possible for a node to determine if the block it transmitted was received correctly without collision by its neighbors. However, since none of the encoded blocks are critical, this is not a deterrent to the correct operation of VANETCODE. A node can always receive more encoded blocks from subsequent broadcasts in its neighborhood. However, a nave broadcast mechanism has the potential of generating unnecessary data traffic and the collisions can have a deleterious effect on network performance. To reduce the probability of collisions, the nodes wait for a random interval after the creation of the encoded block before broadcasting it. Alternately, we can use more sophisticated broadcast mechanisms such as the ones presented in [16] and [15] for improved performance.

The nodes can repeat the encoding process at periodic intervals. A priority based mechanism can also be introduced wherein the waiting time prior to broadcasting can be inversely proportional to the number of blocks that a node possess, i.e., a node which has all the blocks of a particular file will get higher priority to broadcast. Further, in situations where a node has not received sufficient blocks to decode the file, it can explicitly request for additional encoded blocks from its neighbors.

When nodes enter into the communication range of the next gateway, they receive additional encoded blocks from the gateway and subsequently continue exchanging linearly combined blocks with each other.

An important difference when compared with SPAWN is that there is no need for block selection and peer selection. In traditional peer-to-peer swarming protocols, these types of selections play vital roles in the performance of content sharing. In the case of VANTECODE, almost every piece of information is important to every node due to the random encoding. Another advantage of our system over other swarming protocols is that a node does not need to find who the neighbors are; it merely broadcasts the encoded packets and every neighboring node will receive that broadcast and use the received block to decode the file. In addition, our proposed method does not rely on a routing protocol to relay packets to other nodes because each node only communicates with its immediate neighbors, which are only a hop away. This saves the time required to establish a routing path and subsequently improves throughput.

However, there is no free lunch. The computation overhead of decoding n blocks using matrix inversion is $O(n^3)$. Further combining the blocks to reconstruct the original file is an $O(n^2)$ task. However, given the current advances in microelectronics, mobile devices these days have significant computing capabilities and can easily perform complex encoding and decoding operations in real-time. Further, battery power is not an issue in vehicular networks since car batteries can power these devices.

**Table 1: SIMULATION PARAMETERS**

| Parameter | Value |
|---|---|
| Distance between two gateways | 1000m |
| Radio Range | 200m |
| Block Size | 2000KB |
| File Size | 1.6MB |
| Velocity | 1-144km/hour |
| MAC protocol | 802.11 |
| Antenna Type | Omni-directional |
| Radio Propagation Model | Two-Ray Ground |

# 4. SIMULAITON ENVIRONMENT AND RESULT

## 4.1 Simulation Setup

We have evaluated VANETCODE using the ns-2 network simulator [3]. We also compare the performance of our scheme with that achieved by SPAWN. In our implementation of the SPAWN protocol, we use the simpler probabilistic spawn for sending gossip messages. Besides, we have not implemented incentive mechanism in either of these schemes. We plan to study and implement these in future. In our experiments, we consider a simple highway scenario with gateways placed at periodic intervals. We assume that the desired file is divided into eight fixed sized data blocks. For simplicity, we have not introduced any other cross-traffic in the simulation environment. The simulation parameters are shown in Table 1.

In scenario 1, we assume that ten stationary gateways are placed in a row along a straight freeway with a 1000 meters gap in between two nodes. Initially, twenty mobile nodes are placed along a straight line with a separation of 200 meter between successive nodes. The velocity of each node is selected randomly between 1-144 km/hour and is assumed to be constant. It is assumed that all nodes are moving in the same direction. We also assume that all the stationary gateways have all the data blocks of the file available and all vehicles are interested on this file.

We also investigate the performance of these two protocols in a different scenario involving clusters of nodes. In this scenario, the nodes were placed in five groups, each comprised of 4 nodes. The nodes within each group are within the communication range of each other. The velocities of the nodes have been selected randomly between 1-144km/hour. This scenario allows us to study the effect of clustering on the performance of the content distribution schemes.

## 4.2 Download Status

Fig. 3 illustrates the total time required to download the entire file for each of the 20 nodes using both VANETCODE and SPAWN in the first scenario. The graph clearly indicates that the progress of downloads is much faster with our proposed scheme. This can be attributed to the linear coding employed in our scheme for distributing the content.

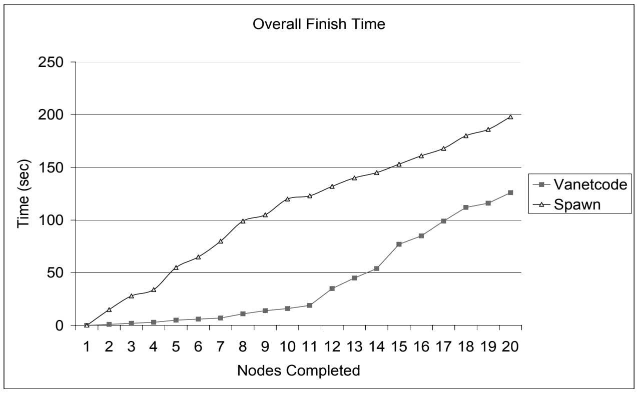


**Figure 3: Comparison of overall finish times for scenario 1**

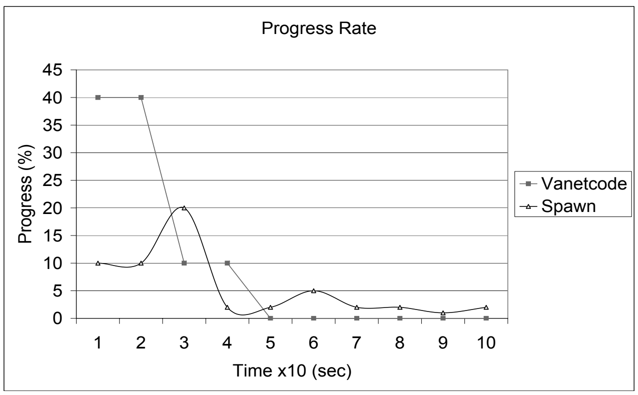


**Figure 4: Comparison of the average progress rate**

As a result, nodes do not have to explicitly wait for rare blocks as in SPAWN. Also, since the nodes can utilize each encoded block that is broadcast in their vicinity, the file is distributed quickly amongst all nodes.

Fig. 4 compares the rate of progress of downloads averaged over all the nodes over time intervals of 10 seconds. As observed with VANETCODE, a large percentage of the blocks are distributed amongst the nodes in the initial time period after startup, largely due to the use of network coding and broadcasting. This implies that the VANETCODE method has better convergence than SPAWN.

Fig. 5 shows the overall download status of the two methods for the second scenario. In particular, we wish to observe the effect of clustering on content distribution. It can be inferred from Fig. 4, that minimizing hops increases the performance of both methods. In VANETCODE, the grouping allows more nodes to receive information from neighbors with fewer broadcasts. As a result, the performance improvement is even better with VANETCODE.

## 4.3 Collisions

Since both VANETCODE and SPAWN utilize link-layer broadcasting it is also important to evaluate the associated overhead in terms of the collisions induced by these schemes. Fig. 6 shows the number of collisions generated for each method. Though the VANETCODE method uses broadcasting to disseminate encoded data blocks, it generates less number of collisions than SPAWN. This is primarily due to the fact that SPAWN requires additional data transmissions due to data block selection, peer selection and neighbor list propagation.

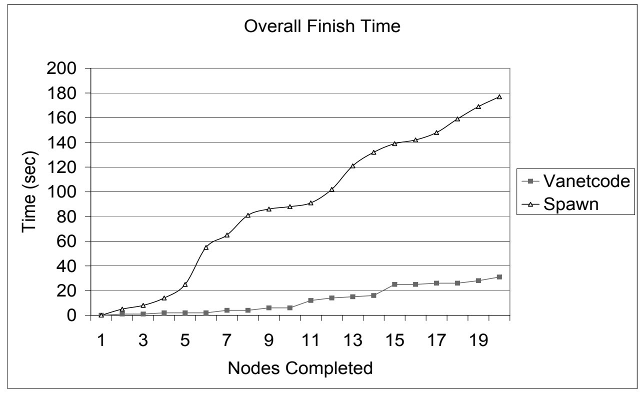


**Figure 5: Comparison of overall finish times for scenario 2**

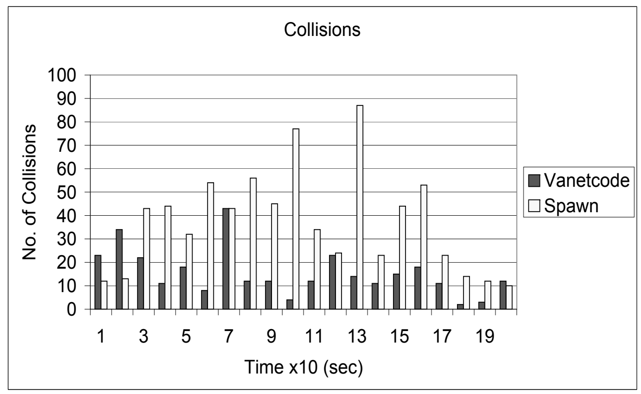


**Figure 6: Comparison of collisions generated in both methods**

# 5. CONCLUSIONS

In this paper, we propose VANETCODE, a novel network coding based content distribution scheme for VANET. Our scheme leverages the broadcasting properties of wireless media and enables quick distribution of the content among the requesting nodes. Using simulations, we illustrate that our scheme achieves improved performance and better convergence in comparison with SPAWN.

The simplified traffic model used here may not reflect the true moblity pattern of the vehicles. We plan to do rigours experiments on real life traffic traces in future. We also want to perform extensive simulations to figure out the optimal block size on real life traffic conditions.

An important problem of peer-to-peer content sharing schemes is free riding, which can seriously degrade the performance [5]. Incentive mechanisms play an important part in countering this. In the future, we intend to extend our scheme to include incentive mechanisms and evaluate their effect on the performance.

# 6. ACKNOWLEDGMENTS

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