Smart infrastructure design for Smart Cities

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Abstract

Intelligent Transportation Systems (ITS) is one of the keywords to describe smart cities, aiming at efficient public transport, smart parking, enhanced road safety, intelligent traffic management, on-vehicle entertainment, and so on. In ITS, Roadside Unit (RSU) deployment should be well-designed due to it serves as a service provider and a gateway to the Internet for vehicular users. In this article, we propose an RSU deployment strategy which maximizes the communication coverage and reduces the energy consumption of RSUs, simultaneously. We first formulate a multi-objective optimization RSU deployment problem and solve it by an evolutionary algorithm. Then we conduct extensive simulations and simulation results demonstrate that our proposed strategy significantly improves both the energy efficiency and the network connectivity.

Keywords-Intelligent Transportation System (ITS), RSU deployment, multi-objective optimization, communication coverage, energy efficiency

I. INTRODUCTION

ICT makes cities "smart" which can manage infrastructures more effectively and efficiently. The smart grid is an example that ICT is applied to a traditional electric grid to make a smarter use of electricity. The intelligent transportation system (ITS) is more familiar example since most of us have benefited from ITS technologies including car navigation and Electronic Toll Collection (ETC). With advances in the automotive and wireless technologies, Vehicular Ad-hoc Networks (VANETs) have emerged to enhance ITS for provisioning a wide spectrum of safety and information applications to drivers and passengers. VANETs can also collect a large amount of data from distributed vehicles for several objectives such as traffic control, safety assistance, and environmental monitoring [1]. Generally, communication in VANETs can be classified into two types: vehicle to vehicle (V2V) communication and vehicle to infrastructure (V2I) communication, as shown in Figure 1. In V2V communication, vehicles equipped with an on-board unit communicate with each other through wireless channels. V2V communication testing has been already started in industry and worldwide automakers, e.g., Toyota [2], Honda [3], Volvo [4], and BMW [5], have developed their own testbed systems. In academia, cooperative downloading and message dissemination using V2V communication have been studied to improve delivery efficiency [6]. Some research efforts have been made to solve security and privacy problems because data transmission through V2V communication may expose personal information of vehicular users to malicious ones [7].

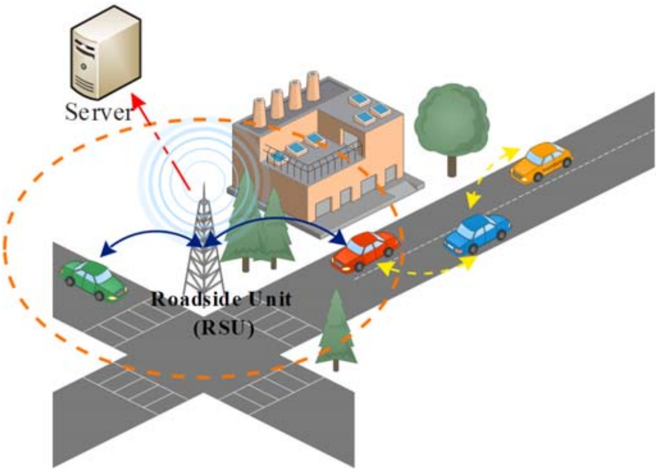

Fig. 1: Vehicle to Vehicle (V2V) communication and Vehicle to Infrastructure (V2I) communication

Meanwhile in V2I communication, the vehicles connect to the Internet through either cellular networks or Road Side Units (RSUs). Usually, with much lower communication cost, vehicles access the Internet through RSUs instead of the cellular networks. In Japan, we can see more than 1000 RSUs deployed mainly around a highway. The RSUs provide information service, currently focusing on safety-related information, for on-road vehicles by the 5.9 GHz Dedicated Short Range Communications (DSRC) spectrum. However, more options are promising to be offered such as entertainment purposes. In the United States, a large budget is allocated for next-generation ITS, e.g., New York City will receive 42 million dollars for upgrading ITS such as traffic signals with V2I technology [8].

With the recent penetration of LTE/Wimax/3G networks, users can enjoy online shopping, check emails, and watch videos even while they drive a vehicle. However, still VANETs are necessary to assist the Internet access in motion by the following reasons. First, capacity of cellular networks almost reaches a limit because of heavy traffic coming from the cellular networks [9]. For this reason, it is costly for most people worldwide to access the Internet via the cellular networks, e.g., average 60 USD/7GB in Japan [10] and 10 USD/1GB in Canada [11]. Second, using a monitor embedded with the vehicle is more safe and convenient than using a small mobile-phone screen when users in motion access to the Internet especially for entertainment purposes. Lastly, mobile phones are battery-powered so that frequently accessing the Internet by a mobile phone uses its energy up so fast, not to mention for video streaming. In addition, it is known that bandwidth fluctuation gives a great impact on energy consumption of a mobile phone [12]. In other words, bad connectivity due to weather, building, or some other factors results in consuming much more energy than good connectivity. Although it can be charged on a vehicle, the equipped device in the vehicle is obviously easier to use than the mobile phones.

Intuitively, the more RSUs will be deployed anywhere in smart cities, the more the quality of life (QoL) improves. However, RSU deployment will be failed because not only initial setup cost is too expensive, but also it will waste much energy consumed by less frequently used RSUs. Energy efficiency cannot be neglected that is another mission of smart cities [13], [14]. On the other hand, if the number of RSUs decreases to save the setup cost and energy consumption, service availability and connectivity may get worse because of limited RSU communication coverage. Thus, there is a trade-off relationship between the energy consumption and communication coverage.

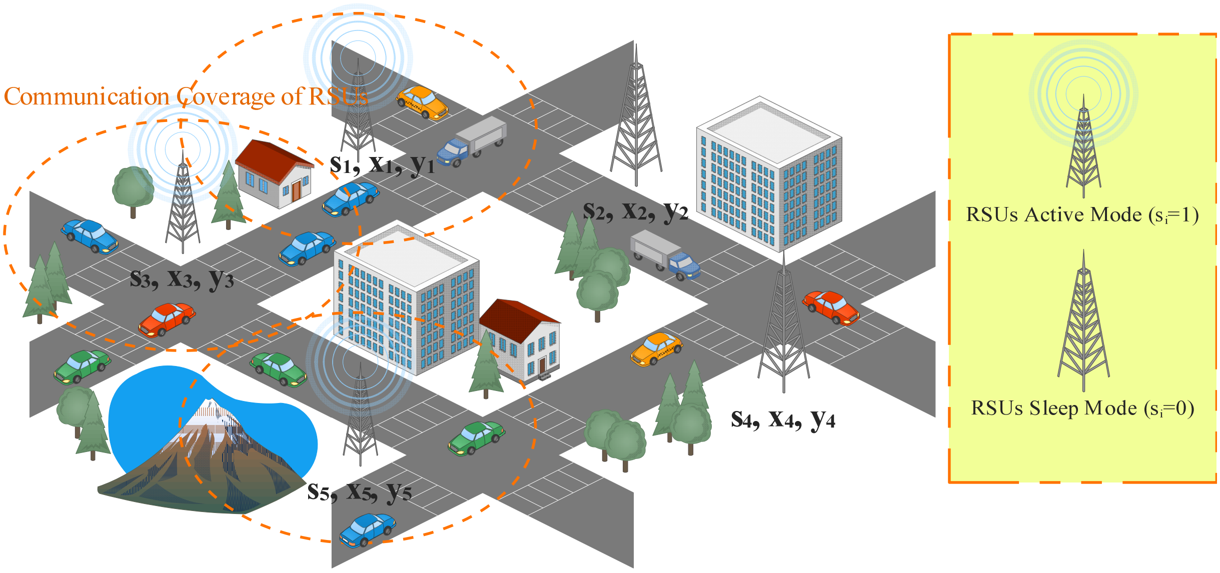

Fig. 2: A model of optimal RSU deployment

In this article, we investigate an RSU deployment problem and formulate them as an optimization problems with multiple objective. Then, we find a solution using the evolutionary algorithm and show that our solution maintains high energy efficiency while guaranteeing communication coverage by extensive simulations.

II. RSU DEPLOYMENT PROBLEM

RSU deployment needs to be well planned because of the following reasons. First, the cost for deployment and operation/management is high, e.g. $13,000-$15,000 per unit and $2,400 per unit per year for deployment and operation/management, respectively [15]. Because of a limited communication range of each RSU, densely deploying RSUs is better to provide service throughout a city; however, service providers may have to set expensive access fee for RSUs that will discourage users from using RSUs. Also once an RSU is deployed, it is not easy to be uninstalled or move to other places. Thus, it is important to balance between the communication coverage and the number of RSUs. In our previous work, we achieved maximizing the communication coverage with a given number of RSUs [16]. It is useful for the service providers to plan the RSU deployment on a limited budget.

TABLE I: Summary of the related works

	Communication Coverage	Energy Efficiency
Lin [17]	X	
Rebai, et al. [18]	X	
Cavalcante, et al. [19]	X	
Kumrai, et al. [16]	X	
Sou [20]		X
Zou, et al. [21]		X
Ours	X	X

Then, the next issue is energy efficiency of RSUs. Although the RSUs are outlet-pugged, waste of energy cannot be ignored with increasing awareness of environmental issues. It will waste huge amount of energy that vehicle traffic density varies temporally as well as spatially. For example, a number of vehicles pass through an RSU deployed at the center of an urban city during daylight; however, almost no vehicles pass through the RSU at midnight. The wast of energy can be avoided by turning RSUs on/off as the situation demands, which should be well studied, otherwise the network connectivity can be degraded seriously. Thus, we study how to minimize the total energy consumption of RSUs while maximizing the overall network connectivity.

The RSU deployment problem has been studied in the literature [17]-[19]. In [17], an author aims at minimizing the cost of RSU deployment with a constraint that all service areas should be covered. It is solved by the branch and bound method and shows that the probability of uncovered areas increases while the average number of required RSUs decreases. In [18], authors propose a new mathematical linear programming to solve the RSU deployment problem. The total network cost and maintaining connectivity between sensors and RSUs are considered in the deployment. The proposed method is effective for solving medium size problems. In [19], a genetic algorithm is proposed to solve maximum coverage with time threshold problem (MCTTP). However, those works do not deal with the energy consumption and the communication connectivity of VANETs. On the other hand, several researches take into account energy efficiency of the RSUs [20], [21]. In [20], an analytic model with linear time complexity is developed for the optimal number of active RSUs under a connectivity constraint. In [21], authors aim at finding the optimal sleeping schedule of RSU within a given time period to minimize the overall energy consumption of RSUs while maintaining the network connectivity. However, none of them does not consider the communication coverage in VANETs. We summarize these related works in Table I.

In this article, we consider the RSU deployment problem as a multi-objective optimization problem where the communication coverage is considered as a constraint, and minimizing the total energy consumption of RSUs and the communication connectivity are considered as two objectives. We use an evolutionary algorithm (EA) to find a solution for this multi-objective optimization problem, which is more efficiently than traditional approaches.

III. RSU DEPLOYMENT OPTIMIZATION

Figure 2 shows a model of optimal RSU deployment. (x_i,y_i) denotes the 2D position of RSU i and binary variable s_i denotes whether RSU i is in active mode or sleep mode. We assume that vehicles are randomly distributed in a target area and each vehicle communicates with an RSU when it moves into the communication coverage. On a road with many vehicles, RSUs always need to be activated for communication with these vehicles to ensure communication connectivity. When the vehicle traffic density decreases, some RSUs can be turned into a sleep mode to lower energy consumption, at the same time, which may result in losing the communication connectivity. Thus, we consider the *communication coverage* as a constraint and minimizing the *total energy consumption* and maximizing the *communication connectivity* as two objectives.

- Communication coverage: We assume that the city is divided to $X \times Y$ grids. When a grid is within a communication coverage of at least one RSU, it is regarded as a communication area. The total communication area is the sum of those grids. Service providers usually require that the VANET should cover some certain areas, that is a communication coverage requirement.
- Total energy consumption: The total energy consumption is energy consumed by all RSUs deployed in the city. The energy consumption of each RSU depends on the RSU's status: active and sleep. Here we only consider two statuses of the RSU and an active RSU consumes much more energy than sleep one.
- Communication connectivity: We compute the communication connectivity from the throughput performance in VANETs. This communication connectivity can be measured as $(P_{R_i})/(P^v)$, where P_{R_i} is the number of data packages that RSU i successfully received from each vehicle, and i=1,..., N_R and P^v

is the total number of packages generated by all vehicle in the city. For simplicity, we assume that data transmission succeeds whenever a vehicle is within a communication coverage of an active RSU.

A. Evolutionary Algorithm

To satisfy the communication coverage requirements, we seek an optimal RSU deployment to minimize the total energy consumption of RSUs and to maximize the communication connectivity. Finding optimal RSU deployment, i.e., combination of RSU positions and status, is an NP-complete problem. In addition, the more the number of RSUs for a big city, the more the search space. For example, there are 150 RSUs for deployment in the city. A communication coverage of each RSU is set as 250 m. These 150 RSUs will be placed in 5×5 km^2 area in the city. Assume that the target area is divided to 50×50 grids and more than one RSU can be placed on a grid. Thus, the number of search combinations is $2 \times 150 \times (50 \times 50)^{150} = 300 \times 2500^{150}$.

Thus, we use EA to find solutions of the RSU deployment problem and Figure 3 shows how the EA works briefly. In this algorithm, we define the population which consists of M individuals. Each individual i in the population represents by multiple segments which is a set of RSU properties. The RSU properties consists of RSU

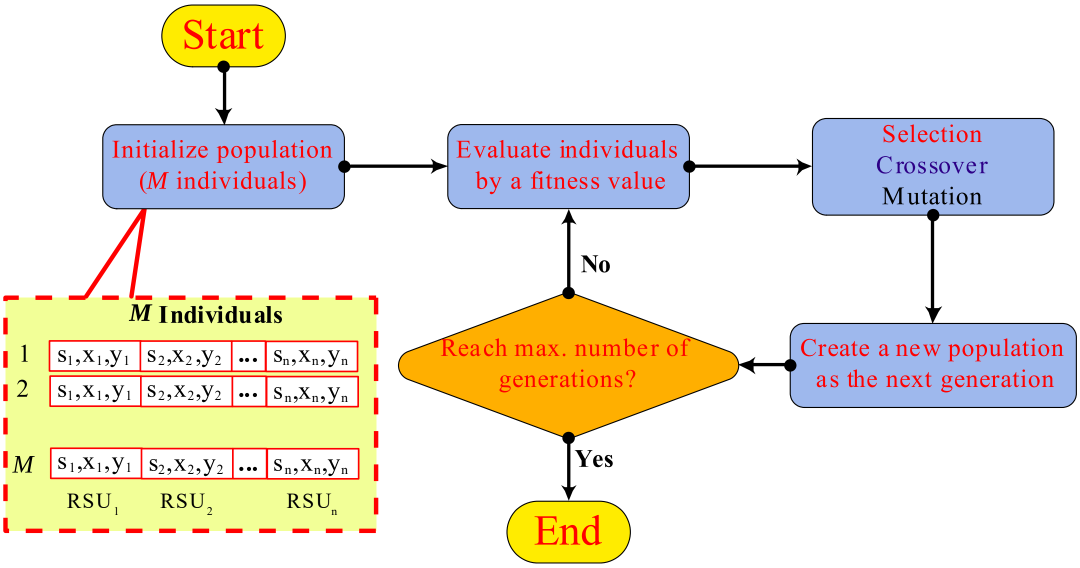

Fig. 3: Brief process of the evolutionary algorithm and an example of individuals

status s_i, RSU location of xi and yi. The number of multiple segments in individual indicate the number of RSUs n in the target area.

First, the initial population will be generated by random RSU properties. Then, the individuals are evaluated by a fitness value which indicates whether the individual is better than others in the population.

Then, the EA selects a pair of individuals who have the highest fitness values as parents. Selected parents reproduce two offspring by a crossover operator with a certain crossover rate. The offspring has an opportunity to mutate with a mutation rate. The mutation rate is a probability that random elements of an individual will be flipped into another value, e.g., flipped from 0 to 1 or vice versa.

The EA repeats these operators (selection, crossover, and mutation) until the number of the offspring achieves size N. Then, this set of the offspring will be combined with the set of the population. Finally, the EA selects the best M individuals from M+N individuals by the selection operator as the new population for the next generation. The selection operator is driven based on fitness values of individuals.

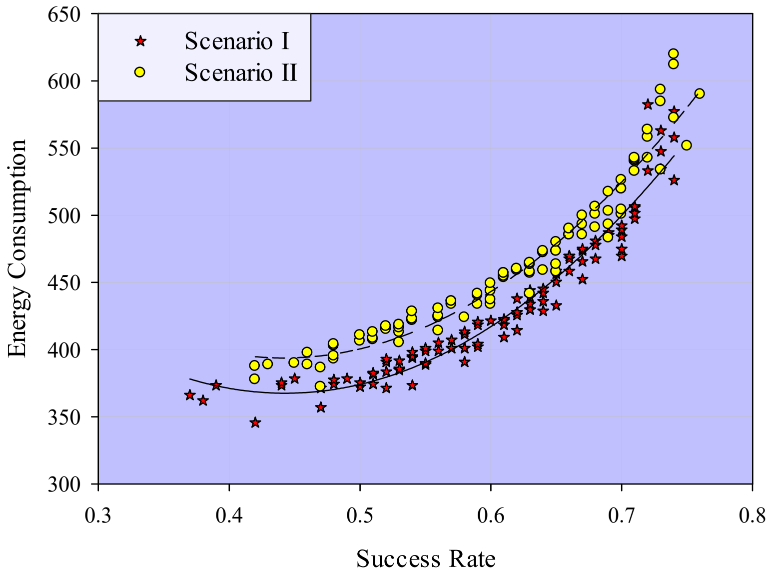

Fig. 4: Performance of the proposed algorithm in energy consumption and success rate

The above process is repeated until the number of the generations reaches the maximum which is decided by service providers. For more details such as how to calculate the fitness values, please refer to our previous work [16].

IV. PERFORMANCE EVALUATION

A. Simulation Setup

We implement VANET simulator to evaluate our proposed algorithm and simulate a 5*km* × 5*km*-sized city with a road length of 53*km*. We divide this city in 50 × 50 grids with a width of 100*m* which is common width of some wide urban roads. We assume that at most 75 RSUs deployed in the city and the RSU communication coverage is set to 250 *m*. The grids covered by RSUs include both full and partially covered ones. The VANET simulator uses the broadcasting routing protocols. The vehicles generate sensing data one packet per second.

The energy consumption of each RSU is derived from the VANET simulator based on the traffic density of roads and corresponding RSU status. We execute the VANET simulator in a period of time and thus calculate the total energy consumption of RSU in the time period. Each RSU can change its status in each second according to the communication coverage requirement.

In our simulations, jMetal [22] is used to execute the EA, which is a simulator for multi-objective optimization problems with meta heuristics. It is an object-oriented JAVA-based framework. The simulation configurations are set as: 100 populations, 2,000 max generations, $1/n$ mutation rate, and 0.9 crossover rate.

In the simulations, we evaluate performance of the proposed algorithm in following two scenarios.

- *Scenario I*: RSU status is variable (i.e., each RSU is either active or sleep)
- *Scenario II*: RSU status is fixed (i.e., all RSUs are active at any time)

B. Simulation Results

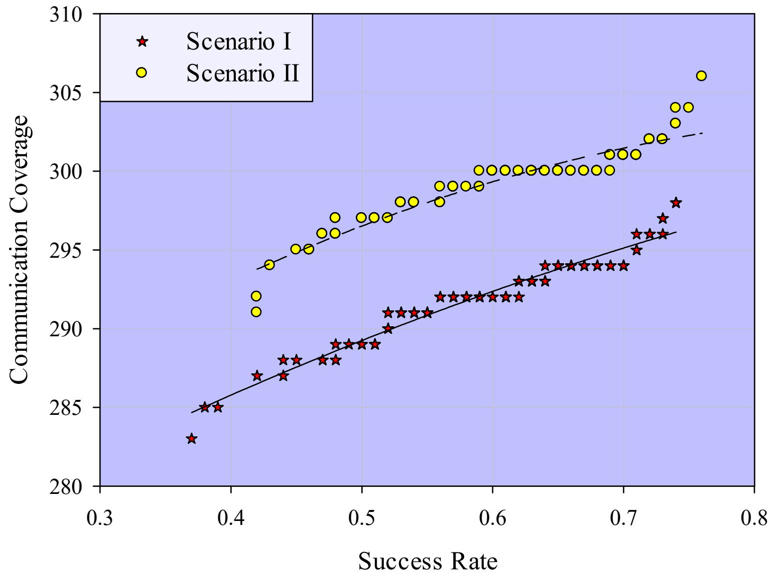

Fig. 5: Performance of the proposed algorithm in coverage and success rate

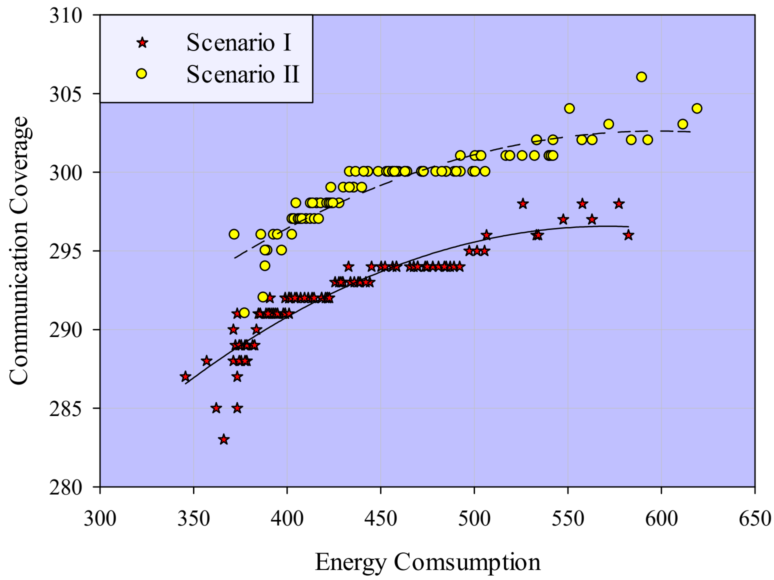

Fig. 6: Performance of the proposed algorithm in coverage and energy consumption

In the simulations, C-metric [23] is used as the performance metric to represent how individuals obtained from one algorithm is better than the individuals from another. $C(A, B)$ represents the C-metric for algorithm A and B, which is calculated by $|\{b \in B | \exists a \in A : a \succ b\}| / |B|$, where operator $\succ$ denotes the dominating (e.g., $a \succ b$ means that individual a dominates individual b). If C-metric = 0, no individual in A dominates individuals in B. On the other hand, if C-metric = 1, at least one individual in A dominates all individuals in B.

Figure 4 shows results of solutions gained by the *Scenario I* and *Scenario II* in two objectives (i.e., the energy consumption and the data transmission success rate). The results show that the RSUs in *Scenario I* consume less energy than ones in *Scenario II*. The average energy consumption decreases by about 7%. Moreover, we show the C-metric at generation 2,000. C(*Scenario I*, *Scenario II*) is equal to 0.78. On the other hand, C(*Scenario II*, *Scenario I*) is equal to 0.00. This result demonstrates that *Scenario I* is better non-dominated frontier than *Scenario II*.

Figure 5 and Figure 6 show the performance of the proposed algorithm in two scenarios, which includes the communication coverage with the communication connectivity and communication coverage with the energy consumption. The RSUs in *Scenario I* cover less target areas while maintaining higher data transmission rate. Since we consider some RSUs sleeping in *Scenario I*, the communication coverage decreases by about 2%. This indicates that the communication connectivity is maintained with properly selected RSUs to be activated.

V. CONCLUSION

This article studies RSU deployment in VANETs which are promising technologies for smart transportation systems. We propose an RSU deployment strategy to optimize the energy consumption of RSUs while guaranteeing an RSU communication coverage requirement. The proposed strategy turns inactive RSUs into sleep mode to save energy while achieving stable access from vehicles to active RSUs. The performance of the proposed strategy is verified by extensive simulations and experimental results demonstrate that our strategy outperforms a traditional algorithm in terms of both energy efficiency and connectivity of VANETs. The proposed strategy is helpful to improve the QoL of people such that online service is always accessible with reasonable access fee on the way of driving. It also enhances energy efficiency of smart transportation systems which may incur additional energy expenditures through VANETs.

We will further conduct experiments under large-scale and realistic simulation setup environments (e.g., using real traffic measurements, using a real city map, and varying the communication range of each RSU) as future work.

ACKNOWLEDGMENT

This work is partially supported by JSPS KAKENHI Grant Number 15K15976, 26730056, JSPS A3 Foresight Program.

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