A Cooperative Social and Vehicular Network and its Dynamic Bandwidth Allocation Algorithms

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***Abstract*— This paper investigates into a special type of network that encourages cooperation between its upper layer social network and lower layer wireless communication network with particular focus on commuters on the road. Regarded as a branch of mobile social networks, the so-called vehicular social network (VSNs) proposed in this paper needs to consider both social aspects (such as social ties through common interests) and physical network operational mechanisms to design a system that is effective to its users and efficient to network resources. This calls for in-depth investigations into the correlation between social behaviours and network algorithms. This paper aims to making some preliminary exploration into this exciting field by investigating into how social centrality, an important concept in social network analysis, makes impact on dynamic bandwidth allocation (DBA) in a specific scenario of vehicular social networks. In particular the paper introduces centrality into the utility function's formula, based on which DBA is carried out in IEEE 802.16j-enable vehicular networks.**

***Keywords*- vehicular social networks, mobile social networks, social centrality, dynamic bandwidth allocation, network cooperation.**

I. INTRODUCTION

A few interesting results about mobile social networks have been reported in the literature [1, 2, 3]. A fairly new type of mobile social network has recently been proposed with specific interest in commuters on the road, namely, vehicular social networks (VSNs) [4]. Vehicles have become an essential part of people's everyday life. As mobile wireless communications go prevalent, people's demand on migrating their office/home computing environment into vehicles in on increase. Doing so will enable people to carry on work or entertainment in a similar setting when they are on the road as either drivers or passengers (or collectively called commuters). This opens up demands for Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V) communications, which render the research field of Vehicular Networks [5]. In vehicular networks, the Internet access from a mobile vehicle, such as a coach or a car, requires roadside infrastructures, such as Base Station (BS) or Road Side Unit (RSU), to enable V2I communications. One particular thing most commuters would like to do during the usually long and boring journey is to socialize with other commuters on the road. These commuters usually travel every working day between home and office on the same roads at roughly the same time day in and day out. Therefore, this is an opportunity for them to form a virtual social community, or so called VSN [4].

While the seminal work on VSN [4] pays emphasis only on a software framework that enables voice chat on roadways, a VSN literally is composed of two fundamental parts that are equally important: a wireless mobile communication network for vehicles (i.e., vehicular network) and a social network framework that runs on top of such a physical vehicular network. Therefore, a VSN requires a neat and inherent cooperation between social aspects (such as social ties through common interests) and physical network operational mechanisms (such as routing, resource management, etc) to design a VSN system that is effective to its users on one hand and efficient in terms of network resources on the other hand. This calls for in-depth investigations into the correlation between social behaviors and network algorithms. This paper aims to making some preliminary exploration into this exciting field by investigating into how social centrality [6], an important concept in social network analysis, makes impact on dynamic bandwidth allocation (DBA) in a VSN scenario.

To support a real-life VSN, a vehicular network such as the one depicted in Figure 1 is needed. In this vehicular network, wireless technology called IEEE 802.16j [7, 8] is utilized as the underlying enabling communication technology. IEEE 802.16j defines relay stations (RSs) and a RS has significantly lower complexity than a standard 802.16 BS. Hence, by using such RSs an operator could deploy a network at a lower cost than using only (thus more) expensive BSs to provide a wide coverage while delivering required service to users. In such a network, a roadside BS serves multiple moving RSs that are within the coverage of the BS, and then a moving RS may further service multiple subscriber stations (SSs) or end users. Here a moving RS can be a coach that carries many passengers on it and each passenger here is regarded as a SS, as illustrated in Figure 1. An SS, i.e., a vehicle equipped with an SS interface in this paper, can also communicate with the BS directly. The BSs are connected to the Internet via Internet Service Gateways. The VSN provider, among other service/content providers, is connected to the Internet. In-vehicle drivers or passengers can have multimedia communications with these providers. One type of provider that is of particular interest of this paper is a VSN provider. This VSN provides a web-based portal for interested users to register and use its social networking services.

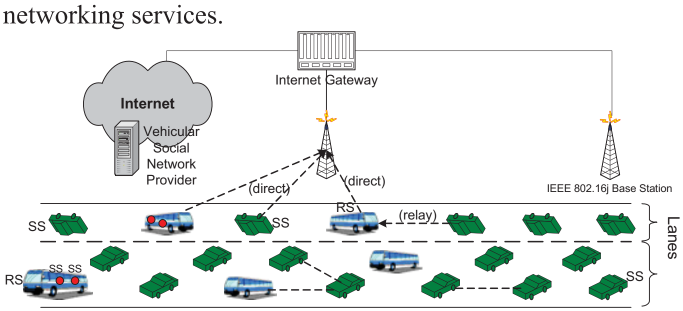

Figure 1 An Example of VSN and its Underlying Network

Given the limited space of the paper, we narrow down to a specific aspect of vehicular network algorithms, i.e., bandwidth allocation, and aim to investigate in the context of traffic relaying how degree centrality can be utilized to assist bandwidth allocation. This paper proposes to use utility function to assist carrying out DBA. In particular the paper introduces centrality into the utility function's formula, based on which DBA is carried out in IEEE 802.16j-enable vehicular networks. This utility function, together with the proposed DBA algorithm, also provides a means to implementing QoS-

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driven service prioritization in the dynamic process of bandwidth allocation. A broader objective of the paper is to investigate into how social centrality, an important concept in social network analysis, makes impact on dynamic bandwidth allocation (DBA) in a particular case such as VSNs. The outcomes of this investigation will serve as the guidance towards more in-depth and thorough research into the correlation between social knowledge and network operation.

The remainder of the paper is organized as follows. Section 2 presents some related work aiming to identifying the unique position of this paper. Section 3 discusses the degree centrality to be used to describe the degree of a RS being used as relay station, based on which the utility function is presented. The details of the proposed DBA algorithms are presented in Section 4. Section 5 contains the evaluation results and discussions. The paper is concluded in Section 6.

II. Related Work

Ref. [4] first introduced the concept of vehicular social networks. It presents a framework for building a particular type of social community, which is to facilitate better communication between commuters driving on roadways. As a proof of concept, it presents a VSN system called RoadSpeak, which allows a driver to automatically join this VSN when he or she is on move and to communicate with other drivers via voice chat messages. This piece work focuses mainly on design of the RoadSpeak application in the context of vehicular networks with little interest in the underlying communication networks. Furthermore, RoadSpeak is concerned about only one type of service, i.e., voice, as it is meant for drivers. In fact, passengers are in an equal (if not more) need for socializing or obtaining information or entertaining themselves in a long journey. Their expected social activities involve not only voice but also text, pictures and videos. Therefore, there are different types of services (text, voice, video, etc) that need to be accommodated by such a VSN. This usually is a concern of QoS (Quality of Service) for mobile wireless networks, of which there is plenty of work. The key point here is how to make best use of the specific features of both vehicular networks and social networks to design more effective and efficient QoS-aware resource allocation algorithms for VSNs. In our previous work [8], we have investigated QoS-aware DBA algorithms for IEEE 802.16-enable vehicular networks. This paper expands these outcomes by embracing social knowledge that is reflected in a concept called centrality. More discussion on how to select an appropriate centrality and how to calculate it is presented later in the paper.

Another inspiring piece of work is [9], which addresses centrality analysis in vehicular ad hoc networks (VANETs). In this paper, centrality is utilized to decide the most efficient (or hotspot) points to deploy RSUs. In contrast, our work tackles a more dynamic problem, i.e., DBA.

There is not much work on VSNs available in the current literature. However, research work on mobile social networks has recently produced a few results, with majority focusing on applications [1-3]. Reference [10] presents a socially-inspired mobility model. This model is developed based on the assumption that mobility patterns are driven by the fact that devices are carried by humans and thus the movement is largely affected by the relationships between humans.

As far as the employed wireless technology is concerned, the majority of the research work on vehicular networks uses IEEE 802.11. This is largely due to the fact that IEEE 802.11 was recommended for dedicated short-range communications (DSRC) system as a default protocol [11]. However, the characteristics of IEEE 802.11 make itself hard to provide QoS supports. The work in [5] introduced the IEEE 802.16 to the vehicular networks because of its appealing characteristics of QoS support and a relatively larger coverage. Our previous work [8] utilizes IEEE 802.16j [7], which is an extension of IEEE 802.16e to support relay mode operation for 802.16 systems. IEEE 802.16j, if compared to the standard IEEE 802.16(e), has advantages of increased coverage and enhanced capacity. Those advantages are achieved through efficient multi-hop links. IEEE 802.16j is employed as the underlying enabling wireless technology for the VSN. Note that in [4], where the concept of VSN was first coined, mobile telecom technology 3G is utilized for proof of the concept.

III. Utility Function

A. Degree Centrality

Centrality is widely used by social network analysis to describe relations among individuals and groups, aiming to identifying the most important actors [9]. An actor is considered to be central if the ties it has with the other actors in the network concerned make the actor more visible or prominent than the others in the network. Looking into the above vehicular network where there are both large coaches and small cars on the road, all communicating to the Internet. Apparently, a coach usually possesses more resources than a car in terms of computational power, storage, communication capability and battery lifetime, etc. As mentioned in Section 1, if relaying via coaches is encouraged then such a vehicular network will demonstrate that coaches tend to have more ties or wireless communication links with other vehicles (especially cars which want to use coaches to relay their traffic). Namely, coaches will exhibit higher centrality.

There are various different types of measures for centralities, such as degree centrality, closeness centrality, betweenness centrality, etc. This paper utilizes degree centrality to express the popularity of a vehicle in terms of relaying as it is intuitive and natural that a coach that has more links (i.e., degrees) with other vehicles is more active or central. In the expression below we use “node” and “vehicle” exchangeably.

The centrality of each node (e.g. SS or RS) is measured by the standardized actor degree index as follows [9]:

$$C_D^{'}(n_i) = \frac{d(n_i)}{N-1} = \frac{\sum_i x_{ij}}{N-1} \quad i,j = 1,2,..,N; i \neq j. \tag{1}$$

where $x_{ij} = 1$ if there is a link between nodes i and j; otherwise, $x_{ij} = 0$. N is the total number of nodes under the coverage of a related roadside BS.

B. Utility Function

As far as the communication demand is concerned, there is a need for nodes that relay more of other nodes’ traffic (such as coaches) to be allocated more bandwidth. However, centrality is not the only factor affecting the bandwidth allocation. There are other two major factors that make impact on bandwidth allocation, i.e., the requested bandwidth from a particular node and the types of services a request is composed of. Combining all these factors, the utility function is defined as follows:

$$U_{i,k}(B_{i,k}^{alloc}) = C_D^{'}(n_i) \times \left(1 - e^{\frac{-\alpha_k \times B_{i,k}^{alloc}}{B_{i,k}^{req} - B_{i,k}^{alloc}}} \right), i = 1,2,....,N; k = 1,2,3. \tag{2}$$

where $U_{i,k}(.)$, $B_{i,k}^{req}$ and $B_{i,k}^{alloc}$ denote the utility, requested bandwidth and allocated bandwidth for service type k on station i respectively. α_k is a weighting factor of different types of services with $k=1,2,3$, corresponding to rtPS, nrtPS and BE services respectively. N is the total number of nodes covered by the BS.

IV. THE PROPOSED DBA ALGORITHM

A. *Criteria of Relaying*

Suppose $r \in \{1,2,....,N\}$ is the sequence number of RS. The signal strength between SS i and the roadside BS is denoted as S_i^{BS}; and signal strength between SS i and its closest RS is detected as S_i^{RS}. The signal strength between the BS and this RS, as detected by this RS, is denoted as S_r^{BS}. The criteria for SS i to relay its traffic to the RS is expressed by the Boolean formula below, which is self-explanatory:

$$(S_i^{BS} \le S_i^{RS}) \,\&\&\, (S_i^{BS} \le S_r^{BS}) = \begin{cases} 1 & relay \\ 0 & no\ relay \end{cases} \quad i \ne r. \tag{3}$$

B. *Explanation of the DBA Operation*

The objective of the proposed DBA algorithm is to allocate bandwidth to different types of services of each SS with QoS considerations from the BS, which is based on the maximizing the total utility of the overall network.

The utility of the overall network is denoted as:

$$\sum_{i=1}^{N}\sum_{k=1}^{3} U_{i,k}(B_{i,k}^{alloc}) \tag{4}$$

The bandwidth allocations to different types of services of each SS make the total utility maximized:

$$Maximize \sum_{i=1}^{N}\sum_{k=1}^{3} U_{i,k}(B_{i,k}^{alloc}) \tag{5}$$

subject to

$$\sum_{i=1}^{N}\sum_{k=1}^{3} B_{i,k}^{alloc} \le C_{BS} - \sum_{i=1}^{N} B_{i,UGS}^{req} \tag{6}$$

$$\text{and} \quad B_{i,k}^{alloc} \le B_{i,k}^{req} \tag{7}$$

where, $B_{i,UGS}^{req}$ is the requested bandwidth of UGS from SS i and C_{BS} is the capacity of the BS.

The derivative of the proposed utility function, Eq. (2), is expressed as $H_{i,k}$:

$$H_{i,k} = \frac{dU(B_{i,k}^{alloc})}{dB_{i,k}^{alloc}} = C_D^{'}(n_i) \times \frac{\alpha_k \times B_{i,k}^{req}}{(B_{i,k}^{req} - B_{i,k}^{alloc})^2} \times e^{\frac{-\alpha_k \times B_{i,k}^{alloc}}{B_{i,k}^{req} - B_{i,k}^{alloc}}} \tag{8}$$

Under the consideration to guarantee the minimum bandwidth requirements of different types of services, the BS first allocates the minimum bandwidth, $B_{i,k}^{\min}$, to service type k (k=1,2,3 representing rtPS, nrtPS and BE respectively) on node i. Refer to our previous work [8] for the means to calculate $B_{i,k}^{\min}$. The remaining bandwidth of BS will be further divided into G parts and each part of bandwidth with amount ΔB_{alloc}:

$$\Delta B_{alloc} = \frac{C_{BS} - \sum_{i=1}^{N} B_{i,UGS}^{req} - \sum_{i=1}^{N}\sum_{k=1}^{3} B_{i,k}^{\min}}{G} \tag{9}$$

The derivative of the utility function with a given value of allocated bandwidth denotes the gradient of the curve at this point. With given allocated bandwidth and certain amount of increment of bandwidth, ΔB_{alloc}, the curve with a bigger gradient at the point of allocated bandwidth shall produce bigger utility increment. To achieve a maximum network utility, the BS should allocate ΔB_{alloc} to the node with bigger utility increment at the point of allocated bandwidth each time.

When the relay happens, the RS is a representative of all the relayed SSs to send bandwidth requests. The bandwidth to relayed SSs can only be allocated to RS, and then it is the responsibility of RS to further allocate bandwidth to its underlying SSs. For simplicity, weighted Fair Queue (WFQ) policy is adopted in the bandwidth allocation from RS to the relayed SSs related to different types of services. The allocated minimum bandwidth of different types of services to RS is also the sum of all the required minimum bandwidth of each relayed SS.

Assuming there are z SSs relayed to the RS. The bandwidth requests of RS are denoted as:

$$B_{r,k}^{req} = \sum_{x=1}^{z} B_{x,k}^{req} \qquad 1 \le z \le N-1; k=1,2,3. \tag{10}$$

And the allocated minimum required bandwidth of RS is further denoted as:

$$B_{r,k}^{\min} = \sum_{x=1}^{z} B_{x,k}^{\min} \qquad 1 \le z \le N-1; k=1,2,3. \tag{11}$$

C. *The proposed DBA Algorithm*

The proposed uplink DBA algorithm operates in the MAC layer of the roadside BS. The DBA module collects bandwidth requests of different types of services from each SS or RS, and based on the proposed algorithm it performs the bandwidth allocations to different types of services. The algorithms are listed as follows.

The Proposed DBA Algorithm:

Input: N, the number of SSs within the coverage of the roadside BS; C_{BS}, the capacity of the roadside BS; α_k, the weighting factors of different types of services; B_i^{UGS}, the bandwidth needed for UGS service of each SS; $B_{i,k}^{req}, i=1,2,...,N; k=1,2,3$, the requested bandwidth of different types of services regarding each SS.

Output: $B_{i,k}^{alloc}$, the allocated bandwidth of different types of services related to each SS.

1. **Initialize:** Collects parameters, and requested bandwidth of different types of services of each SS; collects network parameters, such as total amount of SSs, the capacity of BS.
2. Allocate required minimum bandwidth for different types of services according to their bandwidth requests.
3. *for i=1:N*
4. *for k=1:3*
5. *if B_req(i,k)>0 && C_BS >0*
6. *B_alloc(i,k)=B_min(k);*
7. *C_BS = C_BS - B_min(k);*
8. *else*
9. *B_alloc(i,k)=0;*
10. *end*
11. *end*
12. *end*
13. Calculate ΔB_{alloc} according to Eq. (9).
14. Calculate the derivatives of utility function of different types of services of each RS based on the allocated bandwidth based on Eq. (8) to the sequence $\{H_{i,k}\}$.
15. Sort the sequence $\{H_{i,k}\}$ to the sequence $\{S\}_{3\times(N-z)}$ in a descending order.
16. *for i=1:(N-z)*
17. *for k=1:3*
18. *if H(i,k)==S(i) && C_BS>0*
19. *if B_alloc(i,k)<B_req(i,k)*
20. *B_alloc(i,k)=B_alloc(i,k)+ΔB_alloc;*

21. C_BS=C_BS- ΔB_alloc;
22. else
23. B_alloc(i,k)=B_req(i,k);
24. end
25. return Step 14;
26. else
27. B_alloc(i,k)=B_alloc(i,k);
28. end
29. end
30. end
31. for x=1:z
32. for k=1:3
33. B_alloc(x,k)=B_alloc(r,k)*B_req(x,k)/ $\sum_{x=1}^{z} B\_req(x,k)$
34. end
35. end

In the proposed DBA algorithm, Line 1 is to collect QoS parameters of different types of services, network parameters, such as the total number of SSs entering the coverage of BS and the capacity of BS, requested bandwidth of different types of services of each SS. Lines 2-12 illustrate that the proposed DBA algorithm guarantees the required minimum bandwidth of different types of services based on their requested bandwidth. According to our algorithm, Lines 14-15 create a sequence based on Eq. (8) in a descending order. Lines 16-30 describe how the BS allocates the remaining bandwidth to different types of services. Lines 31-35 describe how the bandwidth related to different types of services of RS is allocated to different types of services of each relayed SSs.

V. EVALUATION RESULTS AND DISCUSSIONS

A. Simulation Setup

In the simulation, vehicles (i.e., RSs, SSs) randomly enter the simulated highway (i.e., the concerned BS) with exponentially distributed inter-arrival time at a rate of 20 vehicles per minute. The ratio between the number of average coaches and the number of average cars is set to 1:25. Vehicle speed follows a Gaussian distribution with a mean of 85km/h and a standard deviation of 10km/h. The capacity of the BS is set to 75Mbps. Channel data rate varies between 5-40Mbps and is a function of distance in our simulation for simplicity. The signal strength is normalized to the value with range 0~1. Transmission ranges of all the vehicles and the BS are 0 ~ 2.4km. Payload of packets varies between 500bytes and 2200bytes.

The performance of the proposed DBA algorithm is evaluated in the following metrics: average queuing delay and throughput. Each point of the curves in the evaluations is obtained by averaging the results from 20 simulation runs. In the simulation, the requested bandwidth of different types of services from each SS follows the exponential distribution with different mean values for different types of services. The mean values of bandwidth requests related to different types of services are set as following:

- Average 512 Kbps of VBR (Variable Bit Rate, rtPS, nrtPS);
- 128 Kbps of self-similar BE traffic.

B. Performance Evaluation

a) Average Queuing Delay

The queuing delay is denoted as the sum of delays encountered by a packet between the time of entering the network and the time of being processed and transmitted. The calculation of average queuing delay is detailed in work [12]. Under different total input traffic load, which can be reflected by different numbers of vehicles, the performance of average queuing delay related to different types of services is evaluated under different traffic load and different centralities of RS.

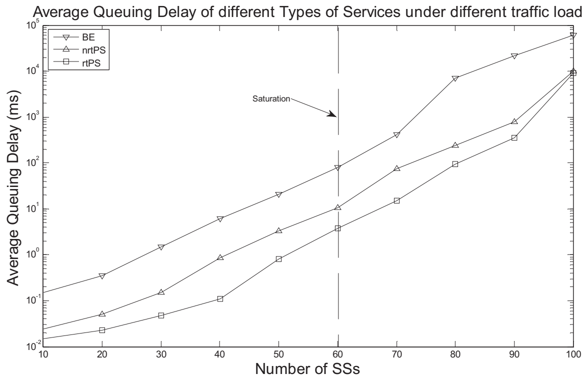

Figure 2 Average Queuing Delays under different traffic load

Firstly, the performance of average queuing delay is evaluated under different traffic load, as shown in Figure 2. As expected, the average queuing delay of different types of services increases as the traffic load increases. Before reaching the saturation point, there is no big difference on average queuing delay among different types of services, and the average queuing delay is increased constantly. This is because the BS can almost accommodate all the packets from SSs and the packets queued in each SS can be served quickly at the next cycle under the condition of light traffic load. However, under the saturation status, the average queuing delay of BE traffic increases most rapidly, and followed immediately by nrtPS. This is because the priority of different types of services is set in a descending order: rtPS, nrtPS and BE, in the proposed DBA algorithm. There is no much difference between the curves of nrtPS and rtPS, this is because the difference of weight factors set for nrtPS and rtPS is not as significant.

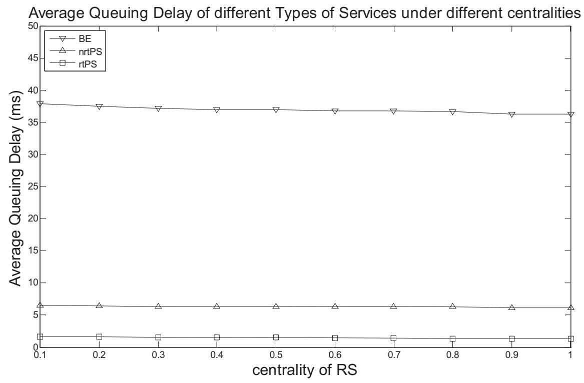

Figure 3 Average Queuing Delays under different centralities of RS

Secondly, the performance of average queuing delay is evaluated under different centralities of RS with a certain traffic load (roughly with 65 SSs – slightly above the number of SSs at the saturation point, which is 60 in Figure 2). As illustrated in Figure 3, the average queuing delay decreases slightly as the centrality of RS increases. This is because the higher centrality of RS means the more SSs are relaying via RSs, and thereby the relayed SSs receive a stronger signal strength and better channel condition. This results in faster packet transmission and therefore a decreased average queuing delay. However, this delay reduction is relatively insensitive to the RS's centralities.

b) Throughput

The performance of throughput related to different types of services is evaluated under different traffic load and different centralities of RS.

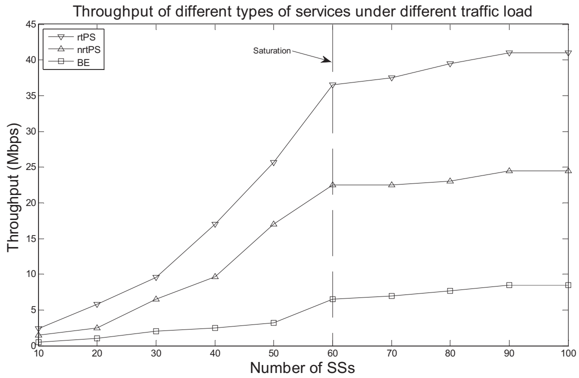

Figure 4 Throughput of different types of services under different traffic load

The curves in Figure 4 illustrates that the throughput of different types of services increases as the traffic load increases. When the system is under the condition of light traffic load (small number of SSs), the throughput of different types of service increases constantly; when the number of SSs increases to a certain value (roughly at 60), the system arrives at a saturation point. Under the saturation condition, the throughput becomes stable and the throughput is as high as about 90% of the capacity of BS. Figure 4 also shows that when the system suffers saturation, the proportion of throughput related to different types of services is nearly in accordance with the proportion of weighting factors of different types of services set in the simulation.

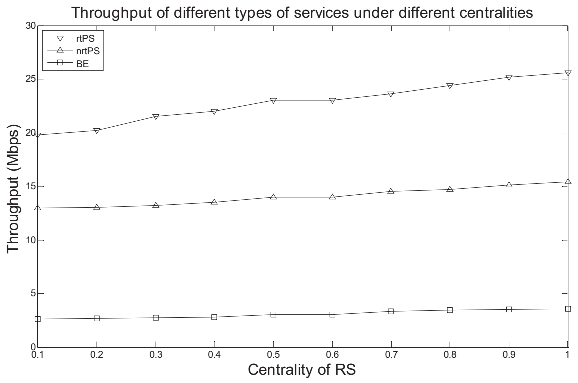

Figure 5 Throughput of different types of services under different centralities

Figure 5 describes that the throughput related to different types of services increases slightly as the centrality of RS increases. As mentioned above, the more SSs are relayed, the better channel condition they benefits, accordingly, higher throughput is achieved. As Figure 5 shown, the rtPS service benefits more throughput, i.e., more bandwidth, than the others; this is because the rtPS is assigned the highest priority, so it could be allocated more benefits achieved through relay.

VI. CONCLUSION

This paper has made some investigation into the correlation between social behaviors and network algorithms in the context of VSNs. In particular the paper explores how social centrality, an important concept in social network analysis, makes impact on DBA in a specific scenario of vehicular social networks. Centrality has been introduced into the utility function's formula, based on which DBA is carried out in IEEE 802.16j-enable vehicular networks. Evaluation results have shown that there is a strong correlation between vehicle centrality and the performance of the proposed QoS-aware DBA algorithm in terms of average queuing delay and throughput.

This paper presents only some initial work on VSNs. Further exploitation of social knowledge of commuter communities for the purpose of wireless network protocol/algorithm design is needed. One of our future works is to incorporate inferred interest from mobility patterns and commuters' social interactions into the DBA algorithm design.

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