Relational Analysis based Concurrent Multipath Transfer over Heterogeneous Vehicular Networks

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Abstract

In recent years, the growing interest in the *Intelligent Transportation Systems* (*ITS*) has resulted in variety of peer-reviewed publications. Significant results in this area have enabled many civilian and industry applications. As more and more vehicles are equipped with multiple network interfaces, how to efficient utilize the coexistence of *Radio Access Technologies* (RAT) such as WiFi, UMTS and WiMAX to serve a best Concurrent Multipath Transfer (CMT) service is still a challenge in ITS. In this paper, we propose GRA-CMT, a novel *Grey Relational Analysis* (GRA) based Concurrent Multipath Transfer, extension for Stream Control Transport Protocol (SCTP). Depending on the advantages of GRA, a *GRA-based Data Distribution* algorithm is proposed in GRA-CMT to calculate the *Grey Relational Coefficient* (GRC) value of all candidate paths and offer a more efficient data scheduling algorithm, a further proposed *GRA-based CMT Retransmission* algorithm devotes to select destination for efficient retransmission. Moreover, the GRA-CMT provides a *GRA-based CMT Path Selection* scheme to manage candidate paths. Sufficient simulation results obtained by a close realistic simulation topology show how GRA-CMT outperforms existing CMT in heterogeneous SCTP-based vehicular networks.

Keywords: *Vehicular networks, Grey Relational Analysis, SCTP, CMT.*

1. Introduction

Vehicular networks has become a very attractive field due to it offers the opportunity to deploy a broad range of innovate, peer-to-peer content sharing and dissemination applications. These applications enable people to reach their destinations in a safe, efficient, and comfortable way. As more and more vehicles are equipped with multiple wireless interfaces, they can intercommunicate with each other using several *radio access technologie*s (*RAT*) such as WiFi, UMTS and WiMAX [1]. However, the coexistence of these RAT technologies in the vehicles raises the challenge of selecting the most appropriate candidate *RAT* to serve a best service due to their high speed mobility and varying distance [2].

With the feature of multi-homing, Stream Control Transport Protocol (SCTP) [3] can support seamlessly, transparently and continuously communication sessions in any heterogeneous network environment which forms of access such as GPRS, 3G, WiFi, WiMax, etc. To provide the dynamic nature of handover in wireless scenario, a SCTP's extension named mSCTP [4] for mobility support is proposed to enable dynamical addition, deletion and change of IP addresses during an activity association. In addition, SCTP provides the feature of Partial Reliability (called PR-SCTP) [5] to differentiate the level of reliability provided to communication messages. Therefore, SCTP will become an expected transport protocol for data distribution in next generation heterogeneous vehicular networks.

Concurrent Multipath Transfer (CMT) [6] extension for SCTP, which uses the SCTP's multi-homing feature to distribute data across multiple end-to-end paths in a multi-homed SCTP association simultaneously, can make vehicles enable multiple radio access technologies to achieve more efficient traffic management, navigation, and user convenience [7][8]. Figure 1 illustrates data distribution with CMT in multi-homed SCTP-based Vehicle Networks. As it is shown in Figure 1, a vehicle can concurrently use UMTS, WAVE and WiMAX radio access technologies to communicate with the server. CMT offers a promising solution which enables the simultaneous use of multiple interfaces to enhance the communication reliability and robustness for multi-homed vehicular networks.

Due to the varying network topology feature of vehicular networks, the condition of wireless access links such as Packet Loss Rate (PLR) and end-to-end delay are

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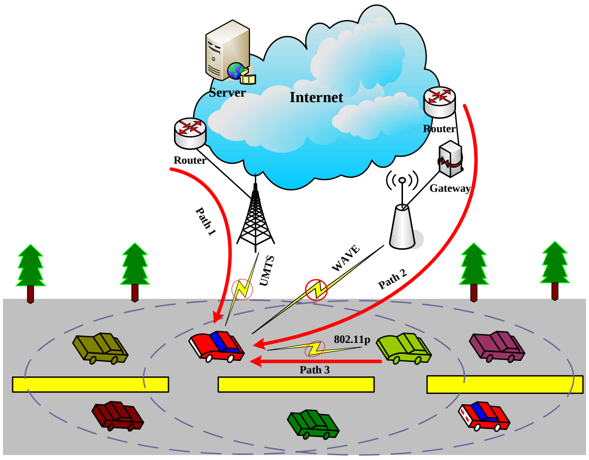

Fig. 1 Concurrent multipath transfer in heterogeneous SCTP-based Vehicle Networks

very common changing in such type of networks. The different heterogeneous condition of each path make the original CMT cannot really achieve the desired communication performance in vehicular networks. The reason is that the original CMT adopts Round-Robin algorithm for scheduling the distribution of flow regardless of the quality of each path. When the conditions of wireless links (UMTS, WiMAX and WiFi) are very different and keep changing, the disorder of packets problem in receiving end will become serious. Since the receive buffer (*rbuf*) is finite, frequent disorder of packet results in receive buffer blocking problems that will drastically decrease the performance of CMT.

Grey Relational Analysis (GRA), derived from Grey System Theory [9], is good at decision making with complicated interrelationships between multiple factors. Motivated by the advantage of GRA, we propose a novel Grey Relational Analysis based Concurrent Multipath Transfer (GRA-CMT), extension for Stream Control Transport Protocol (SCTP). GRA-CMT devotes to calculate the quality of all candidate paths based on Grey Relation Analysis and further offer a more efficient data scheduling algorithm. Moreover, GRA-CMT provides a scheme for candidate path selection. With the candidate path selection scheme, the worst network will be removed from candidate path list if severe receive buffer blocking is detected. With these features, GRA-CMT can achieve high communication reliability and robustness for multi-homed vehicular networks.

The remainder of the paper is organized as follows. In Section II gives related work. Section III details the design of GRA-CMT. In Section IV, the performance of GRA-CMT will be evaluated and analyzed based on a close realistic experimental topology. Section V concludes the paper.

2. Related Work

Path selection for multi-homed vehicular networks attracts more and more attention. Asefi *et al.* [10] proposed a new cross layer path selection scheme with quality of service (QoS) support along urban areas for Vehicular Ad-Hoc Networks (VANETs). Simulation showed that the cross layer path selection scheme can achieve results close to the upper analytical bound. Jang *et al.* [11] proposed an intuitive algorithm named range-aware broadcasting (RAB), the collisions minimized optimal path selection algorithm (CM-Opt), SNR-guaranteed optimal path selection algorithm (SNRG-Opt), low-complexity SNR-guaranteed path selection algorithm (Low-SNRG), and distributed algorithms to reduce the number of collisions and/or reduce the complexity for multi-hop VANETs.

Grey Relational Analysis (GRA) is a promising algorithmic approach that can realize dynamic interface selection with multiple alternatives (interfaces) and attributes. It has broadly used in network selection process. Huszák *et al.* [12] introduced some alternative solutions for GRA to reduce and eliminate the probability of rank inconsistency, caused by the addition or deletion of an interface in multiple interfaces networks. Razzaq *et al.* [13] employed the GRA model into multi-path VANETs to select a more reliable transmission path for text data dissemination while less reliable transmission path for the video data which can tolerate a certain amount of packet loss.

CMT has been regarded as a promising technology for data transfer under stringent bandwidth, delay, and loss wireless environment. In our previous work [14-16], we investigated the performance of multimedia data transfer using CMT over multi-homed wireless networks with the designed Evalvid-CMT platform. Cui *et al.* [17] proposed a Fast SACK (FSACK) scheme which can be applied to both SCTP and CMT-SCTP. With FSACK, the sender can select the optimal return path which serves the data delivery or retransmission. Zhang *et al.* [18] considered Frame Error Rate (FER) at the link layer and Round Trip Time (RTT) at the transport layer to propose a cross-layer scheme for CMT-SCTP.

CMT has become a promising protocol to enhance the performance of communication in multi-homed vehicular networks with capability of distributing data over all available wireless links simultaneously. Huang *et al.* [19] applied CMT into vehicular networks and proposed RG-CMT with goal of providing a fast retransmission for concurrent multipath transfer over wireless vehicular

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networks. With the improved fast retransmission policy to deal with the packet loss, the RG-CMT can improve the communication quality for multi-homed vehicular networks.

Although the advantage of CMT has been investigated in vehicular network, however, existing work still use Round-Robin algorithm for scheduling the distribution of data regardless of the different transmission condition between each path. The blind knowledge from cannot make CMT serve a best service for communication over multi-homed vehicular networks.

3. GRA-CMT Detail Design

This section details the design of GRA-CMT. We first introduce how GRA-CMT devotes to offer efficient data (re)scheduling over selected candidate paths. We assume that the reader is familiar with the Grey Relational Analysis [9].

3.1 GRA-based Data Distribution Algorithm

Accordance with the Grey Relational Analysis (GRA), the path with the largest *Grey Relational Coefficient* (*GRC*) is the one with highest communication quality. To calculate the value of *GRC*, we need to categorize the network parameters first. We assume that each path has k parameters (such as Delay, packet loss rate, bandwidth etc.) used to decide the quality of path. Thus, Delay, packet loss rate, etc. belong to smaller-the-best category while bandwidth, etc. belong to larger-the-best. Before calculating the *GRC* value of each path, the data needs to be normalized to eliminate dimensional units. Assuming that m possible candidate path $(x_1, x_2, x_3, x_4, ..., x_m)$ are compared, we have

$$upper_\alpha = \max\{x_1(\alpha), x_2(\alpha), x_3(\alpha), x_4(\alpha), ..., x_m(\alpha)\} \quad (1)$$

$$lower_\alpha = \min\{x_1(\alpha), x_2(\alpha), x_3(\alpha), x_4(\alpha), ..., x_m(\alpha)\} \quad (2)$$

which $upper_\alpha$ and $lower_\alpha$ denote the upper bound and the lower bound, respectively. $\alpha = 1, 2, 3, 4, ..., k$.

As far small-the-best parameters, the normalized value of $x_i(\alpha)$ can be calculated by

$$\overset{*}{x}_i(\alpha) = \frac{upper_\alpha - x_i(\alpha)}{upper_\alpha - lower_\alpha} \quad (3)$$

In case of the larger-the-best parameters the normalized value can be calculated by following equation:

$$\overset{*}{x}_i(\alpha) = \frac{x_i(\alpha) - lower_\alpha}{upper_\alpha - lower_\alpha} \quad (4)$$

The attributes of path can be represented as a row matrix, where the elements of the matrix are the normalized values of α different path attributes.

$$x = \left[\overset{*}{x}(1)\ \overset{*}{x}(2)\ \overset{*}{x}(3)\ \overset{*}{x}(4)\ ...\ \overset{*}{x}(k)\right] \quad (5)$$

While $\overset{*}{x}_i(\alpha)$ parameters are maximized in 1, and the most preferable network can be always described as $\overset{*}{x}_i(\alpha) = 1$. Using this behavior of the normalizing algorithm, the ideal path is considered as $x = [1\ 1\ 1\ 1\ ...\ 1]$.

If the are M competing available paths to choose from, the previous row matrix (3) can be extended to an $(M \times k)$ matrix, which contains all the parameters that decide the path selection procedure, namely

$$x_M = \begin{bmatrix} \overset{*}{x}_1(1) & \overset{*}{x}_1(2) & \overset{*}{x}_1(3) & \overset{*}{x}_1(4) & ... & \overset{*}{x}_1(k) \\ \overset{*}{x}_2(1) & \overset{*}{x}_2(2) & \overset{*}{x}_2(3) & \overset{*}{x}_1(4) & ... & \overset{*}{x}_2(k) \\ ... & ... & ... & ... & ... & ... \\ \overset{*}{x}_M(1) & \overset{*}{x}_M(2) & \overset{*}{x}_M(3) & \overset{*}{x}_M(4) & ... & \overset{*}{x}_M(k) \end{bmatrix} \quad (6)$$

The final step is to calculate the value of *GRC* via below equation:

$$GRC_i = \frac{1}{\sum_{\alpha=1}^{k} w_\alpha |\overset{*}{x}_i(\alpha) - 1| + 1} \quad (7)$$

which w_α is the weight of each parameter and $i\ (1 \le i \le M)$ is the path index.

Combines the procedure of *GRC* estimation, once having a packet to send, the GRA-CMT will schedule the distribution of data over candidate path with below steps:

1） The GRA-CMT sender calculates the value of GRC_i for each candidate path using equation (7).
2） The GRA-CMT sender sorts the destinations in a descending order of its measured GRC_i.
3） The GRA-CMT sender marks the first destination, namely with the largest GRC_i in the list, as *candidate destination* (denoted as d_{send}).
4） Before transmitting packet, the GRA-CMT sender verifies the *cwnd* of the d_{send}. If the *cwnd* is full, the next destination in the list will be marked as the d_{send}.
5） The GRA-CMT sender distributes the data chunk over the d_{send}.

The pseudo code of the GRA-based data distribution algorithm is illustrated in Algorithm 1.

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Algorithm 1: GRA-based Data Distribution Algorithm

Definition:

d_i: the i^{th} destination within the SCTP association
d_{list}: the active destination list of core node
GRC_i: the GRC value of the i^{th} destination
d_{send}: the candidate path selected to send data chunk

Once having a packet to send, at the GRA-CMT sender side

for all destination d_i **do**
  if status of d_i == ACTIVE **then**
    puts d_i into d_{list};
  end if
end for
for ($i = 1$, $i <= \text{count}(d_{list})$, i++) **do**
  calculates GRC value of d_i in d_{list};
  sorts d_i in an descending by its measured GRC_i;
  sets $d_{send} = d_{list(0)}$;
end for
while *cwnd* of d_{send} is full **do**
  selects destination $d_{send} = d_{send} \rightarrow next$;
end while
end if
schedules the packet over d_{send} for delivery.

3.2 GRA-based Retransmission Policy

Retransmission policy is one of the most key features of CMT to enhance the communication quality under stringent bandwidth, delay, and loss wireless transmission. The original CMT includes five retransmission policies which are dubbed as *RTX-SAME*, *RTX-ASAP*, *RTX-LOSSRATE*, *RTX-SSHRESH* and *RTX-CWND*, respectively. However, accordance with RFC4960, the proposed standard, only *RTX-CWND* and *RTX-SSHRESH* are strongly recommended for CMT while other policies are just for the sake of experiment.

To make our motivation more clearly, we brief the two recommended retransmission policies as follows:

1） With *RTX-CWND* policy, the CMT sender will distribute a retransmission chunk over the destination that has the largest *cwnd* value. If more than one destination has the largest *cwnd* value, then a tie will be broken by random selection by the CMT sender.
2） With *RTX-SSHRESH* policy, the CMT sender will send a retransmission chunk over the destination that has the largest *ssthresh* value. If more than one destination has the largest *ssthresh* value, then a tie will be broken by random selection by the CMT sender.

Combines mentioned above, we note that there is one and same problem exists in the two recommended retransmission policies, that is, if more than one destination has the largest *ssthresh* (or *cwnd*) value, a destination with less satisfied quality (such as stability, robustness) may be selected as retransmission destination by a tie random selection.

Our previous work [20-21] proved that a destination selected by more metrics will have more satisfaction. Inspired by the GRA's advantages on stability and robustness measurement, the *GRC* value of each destination can be considered to combine with *ssthresh* (or *cwnd*) value during retransmission destination selection. In this section, we just base the recommended *RTX-SSHRESH* policy to further propose an improved retransmission policy dubbed as GRA-based retransmission policy. Although we focus exclusively on the *RTX-SSHRESH* policy, the same strategy is also applicable to other retransmission policies.

Once having a retransmission to deliver, our GRA-based retransmission policy will enable following steps to make an efficient data retransmission:

1） A retransmission is sent to the destination that has the largest *ssthresh* value;
2） If more than one destination has the largest *ssthresh* value, then the GRA-CMT sender calculates the value of *GRC* for each destination using equation (7).
3） The GRA-CMT sender distributes the retransmit-needed data chunk over the destination that has the largest *GRC* value.
4） If more than one destination has the largest *GRC* value, then a tie will be broken by random selection by the CMT sender.

The pseudo code of the GRA-based CMT Retransmission policy is illustrated in Algorithm 2.

3.3 GRA-based CMT Path Selection

As mentioned in Section I, when the transmission quality of candidate paths are very different, the disorder of packets issue at the receiver side will become serious. Serious disorder of packet will lead to *rbuf* due to its limitation. The receive buffer blocking (*rbuf*-blocking) problems will drastically decrease the performance of CMT. To avoid deteriorated *rbuf*-blocking issue and achieve a better communication quality of vehicular networks, the design of *rbuf*-blocking avoid scheme for CMT has become urgently.

Several articles [22-23] proved that path selection approach can reduce the *rbuf*-blocking problem, that is, only the selected high quality paths will be used to deliver packets while the paths with deteriorated transmission condition will be removed from candidate path list.

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Algorithm 2: GRA-based CMT Retransmission Algorithm

Definition:

d_i: the i^{th} destination within the SCTP association
d_{list}: the active destination list of core node
$d_i^{ssthresh}$: the *ssthresh* value of the i^{th} destination
d_i^{GRC}: the *GRC* value of the i^{th} destination
$d_{rtxDest}$: the destination selected to retransmit data chunk

Once having data chunk to retransmit, at the GRA-CMT sender side,

for all destination d_i **do**
  if status of d_i == ACTIVE **then**
    puts d_i into d_{list};
  end if
end for
for (i = 1, i < = count(d_{list}), i++) **do**
  if ($d_s^{ssthresh} < d_{list(i)}^{ssthresh}$) **then**
    sets $s = i$; sets $d_s^{ssthresh} = d_{list(i)}^{ssthresh}$;
  end if
  if ($d_t^{GRC} < d_{list(i)}^{GRC}$) **then**
    sets $t = i$; sets $d_t^{GRC} = d_{list(i)}^{GRC}$;
  end if
end for
if! $((d_j \in d_{list}) \&\&(d_j^{ssthresh} == d_s^{ssthresh}) \&\&(j <> s))$
then sets $d_{rtxDest} == d_s$;
if! $((d_j \in d_{list}) \&\&(d_j^{ssthresh} == d_t^{GRC}) \&\&(j <> t))$
then sets $d_{rtxDest} == d_t$;
else sets $d_{rtxDest}$ with random $d_i\ (d_i \in d_{list})$;
A retransmission is sent over the $d_{rtxDest}$.

However, the metric for efficient path selection is the key point but still challenging in wireless concurrent multipath transmission.

Since the GRA is good at decision making with complicated interrelationships between multiple factors, motivated by this feature, we consider the useful GRC value as the metric for path selection and address a resolution named as GRA-based CMT Path Selection (GRA-PS) to make CMT work efficient for multipath transfer in multi-homed vehicular networks.

With GRA-PS, the paths with unsatisfied transmission condition will be removed from candidate path list by the GRA-CMT sender. The GRA-PS follows below workflow to support efficient path selection:

1) If the GRA-CMT sender detects severe *rbuf*-blocking occurred at receiver side, the path with the smallest *GRC* value will be removed from d_{list} and marked as UNACTIVE by the sender.
2) If there is an UNACTIVE path has a greater *GRC* value than the path in d_{list}. Its status will be marked as ACTIVE and putted into d_{list} by the GRA-CMT sender.

The pseudo code of the GRA-based CMT Path Selection algorithm is illustrated in Algorithm 3.

Algorithm 3: GRA-based CMT Path Selection Algorithm

Definition:

ud_{list}: the UNACTIVE destination list of core node
ud_i: the i^{th} UNACTIVE destination within ud_{list}
d_{list}: the ACTIVE destination list of core node
ad_j the j^{th} ACTIVE destination within d_{list}
GRC_i: the *GRC* value of the i^{th} destination

Once the GRA-CMT sender detects serious *rbuf*-blocking occurred at receiver side, at the sender side,

for (j = 1, j<= count(d_{list}), j++) **do**
  calculates *GRC* value of ad_j;
  sorts ad_j in an ascending by its measured GRC_j;
  marks the path $d_{list(0)}$ as UNACTIVE;
end for
for (i = 1, i <= count(ud_{list}), i++) **do**
  calculates *GRC* value of ud_i in ud_{list};
  if the GRC value of ud_i is greater than that of $d_{list(0)}$ within d_{list} **then**
    marks the path ud_i as ACTIVE;
  end if
end for

4. Simulations and Analysis

This section first introduces the design of background traffic used in our experiments. Followed by that, a close realistic simulation topology is presented. With the designed close realistic topology, the performance of GRA-CMT is evaluated with reasonable and sufficient test scenarios.

4.1 Cross-traffic Design

Existing researches on vehicular networks seldom consider background traffic during their performance evaluation. Actually, Internet measurement study [24] showed complex behaviors of Internet traffic that are necessary for the performance evaluation of network protocols. Our previous work [20-21] investigated that cross-traffic can make more side-effect on the performance of CMT as larger value of *rbuf* is used. Therefore, with little or no cross traffic cannot fully reflect the transport protocol behaviors that are likely to be observed when it is deployed in the vehicular networks.

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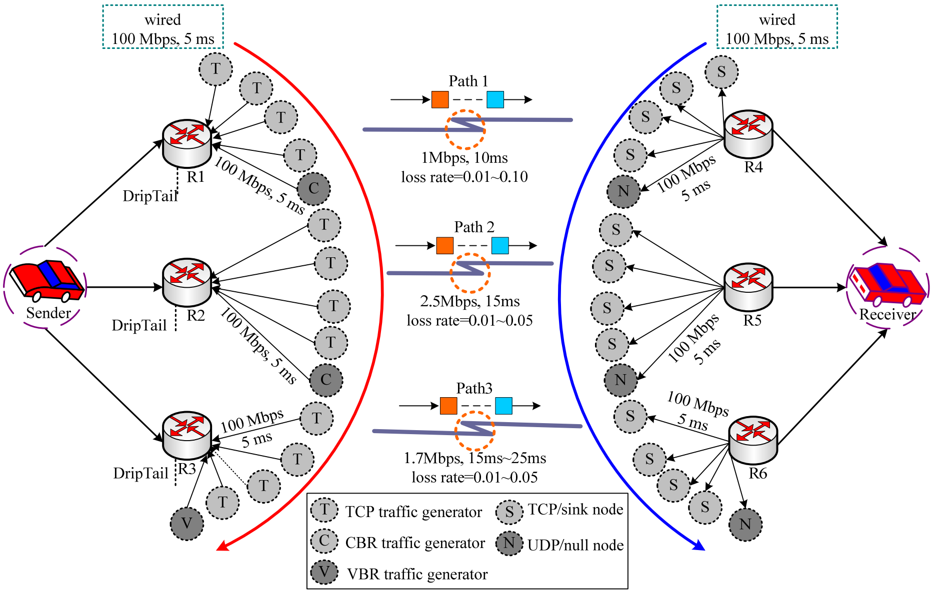

Fig. 2 Simulation Topology

Accordance with the Internet survey [25], TCP traffic on the Internet is about 80%-83%, and UDP traffic is about 17%-20%. Moreover, as variety of attractive services such as multimedia streaming arises in Internet, more and more multimedia content encoded by Variable Bit Rate (VBR) will be deployed in the future vehicular networks. We consider a reasonable cross-traffic composed by TCP traffic, CBR traffic and VBR traffic to investigate the performance of GRA-CMT. To make a realistic experiment scenario, we introduce a realistic Internet traffic gathered from BUPT consisted of FTP traffic, VBR traffic and CBR traffic into NS-2 [26].

To make NS-2 enable VBR traffic generator, we add *PT_VBR* as packet enumeration and then set *VBR* for *PT_VBR*'s value in packet information function [27]. The default values for VBR traffic are set by following Table 1.

Table 1: VBR Traffic Settings

Variable	***Value***
*Application/Traffic/VBR set rate_*	448Kb
*Application/Traffic/VBR set random_*	0
*Application/Traffic/VBR set maxpkts_*	268435456
*Application/Traffic/VBR set maxSize_*	200
*Application/Traffic/VBR set minSize_*	100
*Application/Traffic/VBR set intervaltime_*	200

4.2 Simulation Topology Setup

We use the well-known network simulator NS2 to evaluate the performance of GRA-CMT since the SCTP and CMT protocol have been supported by NS2 well. The simulation topology is shown in Figure 2 and includes the SCTP sender and receiver. Both SCTP nodes have three wireless interfaces.

We assume that there are three wireless access technologies (For example, 802.11p, 3G/UMTS, 4G/WiMAX) used for communication between the SCTP sender and receiver. The Maximum Transmit Unit (MTU) of each path is 1500B. The queue length in all paths is 50 packets. Default receive buffer (*rbuf*) values in commonly used in operating systems today vary from 32KB to 64KB and beyond. So, we compare the performance of the two protocols with an *rbuf* value of 32KB, 64KB, and 128KB, respectively. The GRA-CMT will enable GRA-PS scheme as long as the *rbuf*-blocking reaches 3 times notified from the receiver.

To create a reasonable cross-traffic, we add four TCP generators and one UDP generator for each router to create about 80% TCP traffic and 20% UDP traffic over each transmission path. As it is shown in Figure 2, all FTP/TCP traffic generators, VBR/UDP traffic generators and CBR/UDP traffic generators connect to each router (R1, R2 and R3) respectively with a reasonable bandwidth value of 100Mb, and the propagation delay is 5ms accordance with [28]. All FTP traffic, VBR traffic and CBR traffic are gathered from BUPT. Our simulation will

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stop at 90s. Testing results are calculated by averaging the results of 10 runs with different seeds.

4.3 Performance Evaluations

We present a set of experiments to investigate the performance of GRA-CMT with different *rbuf* values. The throughput and end-to-end (E2E) packet delay are used as metrics to compare the performance of GRA-CMT and the original CMT. For convenience, we illustrate the results of original CMT as "CMT" in test result figures, and the results with our algorithm are illustrated as "GRA-CMT", respectively.

Figure 3 and 4 show the comparisons between the GRA-CMT and the original CMT in terms of throughput and E2E delay with the default *rbuf* value (64KB). Although decision procedures make the GRA-CMT present a worse performance than the original CMT once in a while, for example, the GRA-CMT obtains larger delay than the CMT occasionally in figure 4, however, the GRA-CMT sender can enable the GRA-based Data Distribution algorithm to schedule packets according to paths' GRC value adaptively and start the GRA-based CMT Retransmission algorithm to select destination for efficient retransmission if any. As long as deteriorated transmission condition is detected, the GRA-CMT sender also can launch the GRA-based CMT Path Selection scheme to determine if enables a path for (re)transmission or not. These features make the GRA-CMT outperform the original CMT. The benefit GRA-CMT achieved over that of the original CMT is about 49.71% in terms of mean throughput, and about 1.53% in terms of mean E2E delay.

Due to default *rbuf* values in commonly used in operating systems today vary from 32KB to 64KB, and it becomes increasingly common for a wireless device to be set an *rbuf* value greater than 64KB in further vehicular networks. Therefore, we present a set of experiments with varied *rbuf* values at 32KB, 128KB to investigate the performance of GRA-CMT sufficiently.

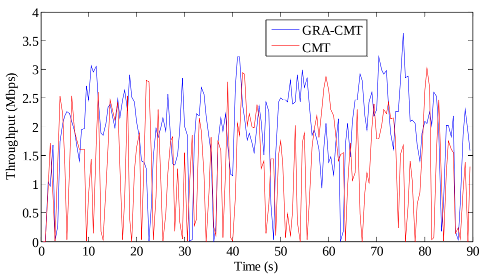

Fig. 3 Comparison on throughput with *rbuf*=64KB

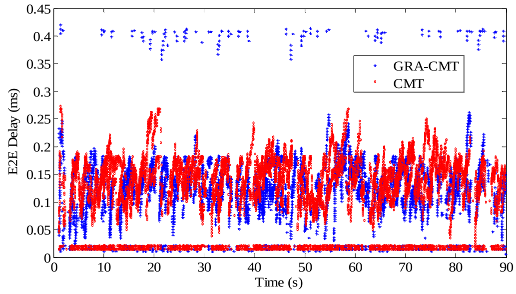

Fig. 4 Comparison on end-to-end delay with rbuf=64KB

Figure 5 and 6 show the comparisons between the GRA-CMT and the original CMT in terms of mean throughput and mean E2E delay under varied *rbuf* value (32KB and 128KB). As shown in the two figures, we can observe that the GRA-CMT achieves better performance than the original CMT under different *rbuf* values.

1） As far the comparison of E2E throughput, Figure 5 shows that both of the two protocols can obtain higher E2E throughput as larger *rbuf* values are used. At the other hand, associated with competition of cross-traffic, either the GRA-CMT or the original CMT cannot gain a very obvious increase when a larger *rbuf* is employed. However, The GRA-CMT works more efficient on data delivery due to its data (re)scheduling scheme.
We calculate the comparison on mean throughput between the GRA-CMT and the original CMT (as shown in Figure 7), the benefit the GRA-CMT achieved over that of the original CMT is about 90.77%, 49.71%, and 15.76% in terms of mean throughput under an *rbuf* value at 32KB, 64KB and 128KB, respectively.

2） As far the comparison of E2E delay, Figure 6 shows that both the GRA-CMT and the original CMT are ascended in the relationship with the *rbuf* value. This is reasonable since more TCP traffic and UDP traffic consume the bandwidth as a larger *rbuf* values is used. However, The GRA-CMT outperforms the original CMT with different *rbuf* values (32KB, 64KB and 128KB).
We also calculate the comparison on mean E2E delay between the GRA-CMT and the original CMT (as shown in Figure 8), the benefit the GRA-CMT achieved over that of the original CMT is 0.23%, 1.53%, and 8.31%, respectively.

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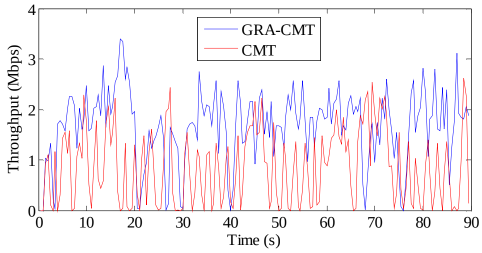

Fig. 5 Comparison on throughput with *rbuf*=32KB

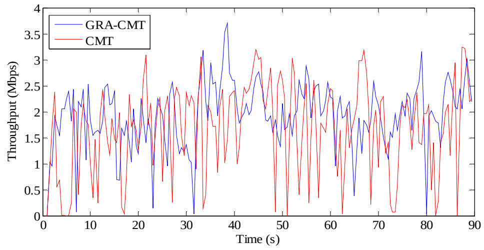

Fig. 6 Comparison on throughput with *rbuf*=128KB

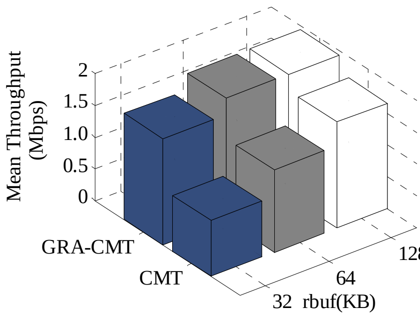

Fig. 7 Comparison on mean E2E throughput under different *rbuf* values

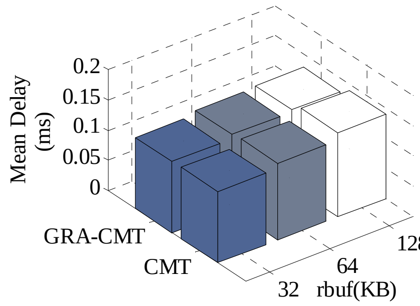

Fig. 8 Comparison on mean E2E delay under different *rbuf* values

Combing the above experimenting, the GRA-CMT can achieve more benefits in terms of data delivery than existing CMT and it is good protocol selected for data distribution over heterogeneous SCTP-based vehicular networks.

5. Conclusions

As more and more vehicles are equipped with multiple network interfaces, Concurrent Multipath Transfer (CMT) has recognized as a promising protocol to efficient utilize the coexistence of *Radio Access Technologies* (RAT) such as WiFi, UMTS and WiMAX in vehicular networks. In this paper, we proposed a novel *Grey Relational Analysis* based Concurrent Multipath Transfer (GRA-CMT). Thanks to the advantages of GRA, a *GRA-based Data Distribution* algorithm was proposed in GRA-CMT with goal of calculating the *Grey Relational Coefficient* (*GRC*) value of all candidate paths and offering a more efficient data scheduling algorithm, a further proposed *GRA-based CMT Retransmission* algorithm devoted to select destination for efficient retransmission. Moreover, the GRA-CMT provided a *GRA-based CMT Path Selection* scheme to determine if enable a path for (re)transmission or not. We designed a close realistic simulation topology to investigate the performance of GRA-CMT. Sufficient simulation results showed the GRA-CMT can achieve higher communication reliability and robustness than existing CMT in heterogeneous SCTP-based vehicular networks.

Since the content-rich multimedia streaming, such as Video-on-Demand (VoD) [29] will be the most attractive services in the next generation networks, our future work will focus on cross-layer multimedia streaming content delivery over multi-homed Heterogeneous vehicular networks. We will consider key parameters both at transport layer and MAC layer to design a GRA-based paths evaluation and selection for wireless heterogeneous vehicular networks.

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