Service and Communication Management in Cooperative Vehicular Networks

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Abstract. With the increasing demand for traffic safety and efficiency and constant search for innovative solutions within the automotive market coupled with supporting initiatives from regulatory domains, the potential of Intelligent Transportation Systems (ITS) is immense. Basic vehicle and roadside infrastructure collaboration allows an increase in efficiency and safety and acts as the foundation for an extensive application set to achieve the ITS goals of cleaner, safer and more efficient travel. There are some important considerations however. Taking into account the wide array of communication technologies and plethora of proposed applications, this paper aims to address one of the major and largely unexplored challenges facing the ITS research community in relation to service and communication management (SCM), whereby the underlying communications capability is sufficiently exploited to assure satisfactory operation of deployed ITS applications. A complete SCM solution is proposed under an "Always Satisfactorily Connected" (ASC) objective; two probing techniques are examined to assess the performance of the candidate communication networks and simple policy and Grey Relational Analysis (GRA) based selection policies are considered. In addition, a standard indicative measure to analyse the effectiveness of the SCM scheme is introduced. The performance of the proposed SCM schemes is evaluated using CALMNet, a comprehensive network-centric simulation environment for CALM-based cooperative vehicular systems. Results highlight the effect of different techniques on system performance and user satisfaction.

Keywords: Cooperative Vehicular systems, ITS, CALM, VANET, Network Selection, Heterogeneous Networks.

1 Introduction

The concept of Intelligent Transportation Systems (ITS) presents new R&D challenges in the transportation and ICT sectors and is currently receiving considerable interest from the research community. The primary objective of ITS is the creation of advanced road traffic systems for improved traffic safety, efficiency, and travelling comfort. Basic vehicle and roadside infrastructure collaboration allow for an increase in efficiency and safety and acts as the foundation for

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an extensive application set to achieve ITS goals. Allowing cooperation among ITS entities to the degree envisioned requires a persistent, stable and reliable underlying communications service.

The ITS community are working towards a full-scale system solution for the provision of value-added services, all of which are fundamentally based on the vehicle-to-vehicle (V2V), vehicle-to-roadside (V2R) and vehicle-to-infrastructure (V2I) information exchange paradigm. Bodies including the Institute of Electrical and Electronic Engineers (IEEE), International Standards Organisation (ISO) and Car-to-Car Communications Consortium (C2CCC), among others, propose communications solutions to facilitate the envisaged ITS operational capabilities where a diverse spectrum of applications are supported [1,2,3]. The ISO propose CALM (Continuous Air-interface for Long to Medium range), a complete high speed ITS communication solution using a heterogeneous mix of new and existing complementary media, enabling V2V, V2R and V2I communication modes providing terrestrial, regional and short range connectivity alternatives [3].

In parallel with the ISO and IEEE standardisation efforts, organisations such as the European Telecommunications Standards Institute (ETSI) and the C2CCC, as well as a large number of funded research projects and commercial content providers have identified many beneficial application and service concepts [4,5,6,7,8]. Considering the heterogeneous mix of communication technologies and plethora of proposed applications, it is possible that at any one time there are multiple mobile network service options available. Selection of an inappropriate network interface or dissemination strategy for data transmission can result in unsatisfactory performance in terms of user or service requirements and constraints, having potentially fatal consequences in the vehicular environment. Identification of the most appropriate transmission strategy therefore becomes a fundamentally important element of any ITS communication solution and directly impacts the perceived system performance. The ultimate challenge is to properly specify the communication requirements of projected ITS applications and derive the corresponding dissemination strategy based on these, taking into account the user preferences and current environmental context.

The remainder of this paper is structured as follows. The next section reviews research efforts in the area of access network selection in heterogeneous network environments. In Section 3, the complete SCM solution is proposed under an "Always Satisfactorily Connected" (ASC) objective; two probing techniques are examined to assess the performance of the candidate communication networks and multiple selection policies are considered. Section 4 introduces CALMnet, the comprehensive simulation environment used for evaluation of various selection approaches in the cooperative vehicular environment. Both quantitative and qualitative analysis of results is carried out in Section 5. In addition, standard indicative measures to analyse the effectiveness of the SCM scheme are introduced. Conclusions are drawn in Section 6.

2 Candidate Network Selection in Heterogeneous Networks

The issue of heterogeneous network management has been studied comprehensively in recent years, with most emphasis on the integration of cellular technologies and WLAN with cellular networks. While the vehicular network solution combines both ad-hoc and infrastructure based communication modes and integration on a larger scale than that previously proposed, the subject of communications management in terms of selection of the best alternative given multiple candidate networks remains.

Network selection involves the implementation of some decision-making policy within the multi-access environment. Design of a complete network selection solution involves four key considerations:

- *Selection Objectives*
  Definition of the "best" network is a core task and drives the solution design process. Therefore, the objectives of the selection system must be clearly defined; will the preferred solution be that which maximises profits, minimises monetary cost or power consumption, optimises QoS, or a combination of these, for example. Typically, the overall objective is multi-dimensional and specific to the system operating environment. Resolution of the overall system objectives will identify the criteria integral to the decision making process. [10,11,12]
- *Parameter Significance*
  Network selection is often a trade off between multiple factors in order to achieve the cited objectives. Therefore, it is necessary to identify the relative significance of the decision criteria; each should be assigned a weighting value proportional to the magnitude it endows on the decision. Parameter weighting can be fixed or dynamically adjusted in relation to the situational context, can be set by user or application, and in some cases utilises fuzzy logic or analytic hierarchy process (AHP) techniques. [10,13,14,15]
- *Condition Monitoring*
  The network selection policy generally relies on a number of static and dynamically changing metrics. A good solution should ensure that information regarding current conditions is suitably accurate. This requires an information gathering process where all parameter values can be quantified and is fundamentally dependent on the selection deployment strategy. The use of network-assisted selection solutions for example, is one approach for data monitoring, while machine learning and user rating propagation (i.e. gossiping) techniques have also been proposed. [11,17,18]
- *Candidate Ranking*
  Once the relevant information has been gathered, all candidates are ranked in relation to their ability to meet the identified selection objectives. This is achieved through simple fixed policies or more complex techniques employing fuzzy logic theory, cost and utility functions, game theory, or other multi-attribute decision making (MADM) techniques including GRA, TOPSIS, and ELECTRE. [10,11,15,16]

These considerations should be used as the template for complete system design in a heterogeneous network setting. The following section describes the proposed SCM approach.

3 Service and Communication Management for Cooperative Vehicular Systems

In the literature, few studies propose a complete network selection solution; most concentrate their efforts on the ranking of candidates for a given objective/parameter set. This paper proposes the SCM framework; a complete solution for cooperative vehicular environments which is directly applicable to the ISO CALM stack. Here, two communication interfaces (CI) are assumed. UMTS provides a wide area cellular connection facilitating V2I communication while 802.11p WAVE is employed for V2V and V2R connectivity.

3.1 Selection Objectives

The principal objective of any system for the ITS scenario will be in ensuring adequate service provision; this prompts a move away from the traditional "Always Best Connected" (ABC) paradigm, so dominant throughout the literature, towards the concept of "Always Satisfactorily Connected" (ASC). In this case, the "best" is defined as that candidate which most closely satisfies user preference and the operational requirements of the requesting services rather than that which maximises these.

Application data in vehicular networks has spatiotemporal properties; all information has a finite lifetime and is typically only relevant to specific geographic areas. Should the intended destination receive stale or spatially non-relevant information, then ITS service requirements may be compromised. Reliability also has elevated importance in the ITS scenario; the loss of information can have considerable consequences. It is obvious then that the application requirements will centre on data lifetime and reliability requirements. Data lifetime defines the time after which the data becomes stale and is of no relevance to the receiver any longer; reliability describes the loss tolerance for each deployed service.

User preference in the form of cost will also have a significant impact on selection of a suitable carrier network and will often dictate the selection decision. This cost can be expressed in monetary or data usage terms. Here, users specify their willingness to pay (WTP) in relation to the offered ITS services and the selection strategy must strive to satisfy this.

3.2 Parameter Significance

Given the large scope for development in the ITS domain and the diverse set of applications that will be deployed, it is necessary to classify the service sets in relation to their operational requirements. This enables the SCM to identify the parameter significance for a given set of services. In this study, three classes are defined; these are generic categories within which individual applications can be specified.

- Safety Services
  This category encompasses a variety of applications necessary for improved safety and traffic management. Such services include collision, hazard and emergency vehicle approach warnings, as well as information regarding dynamic speed limits, lane usage and traffic light state notification etc. Applications in this service category have very strict spatiotemporal properties; data has a short lifetime and is relevant only at a local level. In this category, information is generally transmitted via broadcast communication.
- Subscriber Services
  This includes a number of commercial and informational services to which a traveller can subscribe. Drivers may wish to receive information regarding the traffic state on their chosen route to a particular destination, for example. Commercial advertising and vehicle platooning are also envisaged as subscriber based services where travellers express interest in receiving certain update information. This category comprises of an information push based model where notification data is delivered to subscribed users; temporal and reliability constraints are more relaxed than those defined for the safety service.
- Personalised Services
  This category encompasses applications which cater for individual traveller requirements. Transaction based services such as parking space reservation and temporary bus lane usage, as well as route planning applications and commercial vehicle agent systems fall into the category of personalised services. This class of services has strict requirements relating to reliability while data has longer lifetimes.

3.3 Condition Monitoring

Candidate ranking is fundamentally dependent on the quality of the context information regarding current network conditions. Therefore, the quantification of parameters which reflect this is a cornerstone in any network selection strategy. Here, two approaches to candidate condition monitoring are considered:

- Constant Probing takes into consideration the general performance of each candidate network over time. This is based on the CVIS-CALM implemented approach whereby the vehicle Mobile IP Home Agent (HA) is periodically polled using ICMP Echo Request messages. Network latency, jitter, throughput and loss information is recorded and weighted sliding window analysis calculates updated performance indicators for these.
- Dynamic Probing reports on the performance of the direct communication path between source and destination endpoints. This approach also uses ICMP Echo Request messages to determine the latency, jitter, throughput and loss performance of each candidate network. This polling is aperiodic; probing is initiated with every new service request and the intended destination for the calling service is polled.

3.4 Candidate Ranking

Once the relevant information has been gathered, all candidates must be ranked in relation to their ability to meet the identified selection objectives. In this study, a GRA based approach is proposed. This has been shown to be the best MADM technique for network selection since reference solutions can be customised for a varying mix of attributes and optimisation objectives [19].

Grey Relational Analysis (GRA) is a well-known MADM technique, used across many disciplines, which measures the strength of the relationship between data sequences. Here, the set of criteria $\{k_1, k_2...k_n\}$ for each of the alternatives $\{x_1, x_2...x_m\}$, are represented by the decision matrix, D

$$D = \begin{vmatrix} x_0(k_1) & x_0(k_2) & \dots & x_0(k_n) \\ x_1(k_1) & x_1(k_2) & \dots & x_1(k_n) \\ \vdots & \vdots & \vdots & \vdots \\ x_m(k_1) & x_m(k_2) & \dots & x_m(k_n) \end{vmatrix} \tag{1}$$

A reference solution, x_0, is also defined, to which all candidates are compared. D is normalised, becoming D', typically following a larger-the-better, smaller-the-better or nominal-is-best normalisation policy. The Grey Relational Grade (GRG),η, used to describe the similarity between each candidate network x_i, and x_0, is then computed using the following:

$$\eta = \frac{1}{n} \sum_{i=1}^{n} \frac{\Delta_{min} + \Delta_{max}}{\Delta_i + \Delta_{max}} \tag{2}$$

where
n $=$ number of decision criteria
$\Delta_i = |x_0(k) - x_i(k)|$
$\Delta_{max} = \max(\Delta_i)$
$\Delta_{min} = \min(\Delta_i)$

The GRG identifies the distance to the reference solution and therefore the alternative achieving the highest GRG score is deemed the most suitable candidate.

Determining a suitable data dissemination alternative for the GRA-based SCM is a three stage process involving the following tasks:

1. Definition of reference solution, x_0
   This represents the ideal solution with which all candidates x_i are compared. In an effort to ensure the ASC objective, here x_0 is taken to be the operating requirements of the requesting applications. Therefore, x_0 is defined dynamically with every communication request from upper layer ITS applications. This provides a flexible SCM solution which can cater for a diverse mix of newly deployed and existing ITS services and also ensures the ASC objective.

2. Criteria Normalisation
This involves expressing and evaluating the observed network conditions in a form where they can be easily compared. In this study, the criteria are normalised with respect to the reference solution, x_0. Normalisation therefore, is a measure of the degree of fulfilment of the ITS service requirements by the network characteristics and is calculated using a set of utility functions. Since the objective of the proposed SCM solution is ASC, the nature of these utility functions is dependent on the service category and the requirement under consideration. The normalised value, δ, is then used to calculate the GRG score. The utility functions are designed so that only exact matches for x_0 are awarded the highest δ of 1. For candidates which cannot meet or exceed x_0, δ is negatively assessed with varying degree; those unable to meet the requirements experience sharper decay than those which can exceed them and is based on the distance between the reported performance and x_0. For this reason the utilities are modelled using exponential behaviour.
   - *Safety*
     Safety services are of the highest priority in the ITS environment; these applications broadcast information at frequency f_{safety} and have strict temporal requirements. Network delay and loss statistics reported by the network monitoring process are normalised for safety services using the utility functions in (3) and (4) respectively. Safety services have a hard upper limit on the lifetime of data ($x_0(d)$); therefore, any network delay value satisfying this requirement is normalised to 1. Network delay values exceeding $x_0(d)$ achieve a zero utility. Safety services also require 100% reliability; this means that all neighbouring vehicles should receive the data at least once within its lifetime. In equation 4, the smaller the $x_i(l)$, the greater the normalised value, $\delta_{safety}(l)$. For increasing $x_i(l)$, $\delta_{safety}(l)$ decays exponentially, the rate of which is dictated by the frequency, f_{safety}, at which the data is broadcast, and the decay constant,τ_{safety}.

$$\delta_{safety}(d) = \begin{cases} 1 & x_i(d) <= x_0(d) \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

$$\delta_{safety}(l) = e^{-\frac{x_i(l)}{f_{safety} * \tau_{safety}}} \tag{4}$$

   - *Subscriber*
     Subscriber services have longer data lifetimes and are somewhat tolerant of fluctuations in reliability. Following the ASC objective, equations 5 and 6 are designed to ensure that the highest normalised value is the one which most closely matches x_0. For network delay, the maximum normalised value, ($\delta_{sub}(d)$) of 1 is achieved as the delay value approaches $x_0(d)$ at a rate defined by the distance from $x_0(d)$ and $\tau_{sub}^{in(d)}$. For values exceeding the maximum data lifetime, $x_0(d)$, $\delta_{sub}(d)$ exponentially decreases at a rate of $\tau_{sub}^{dc(d)}$. Candidates whose reported losses are within the limits defined in $x_0(l)$ achieve the maximum normalised value, $\delta_{sub}(l)$.

Losses that exceed this threshold cause an exponential decrease in $\delta_{sub}(l)$ according to the distance from $x_0(l)$ and constant $\tau_{sub}^{dc(l)}$.

$$\delta_{sub}(d) = \begin{cases} e^{-\frac{(x_0(d)-x_i(d))*\tau_{sub}^{in(d)}}{x_i(d)}} & x_i(d) <= x_0(d) \\ e^{-(x_i(d)-x_0(d))*\tau_{sub}^{dc(d)}} & \text{otherwise} \end{cases} \quad (5)$$

$$\delta_{sub}(l) = \begin{cases} 1 & x_i(l) <= x_0(l) \\ e^{-(x_i(l)-x_0(l))*\tau_{sub}^{in(l)}} & \text{otherwise} \end{cases} \quad (6)$$

- *Personalised*
  The personalised service category is sensitive to network reliability and data lifetimes are bounded. Network delay values falling in the range [0,$x_0(d)$] achieve a utility score, $\delta_{pers}(d)$, approaching 1 as dictated by the constant $\tau_{pers}^{in(d)}$ and the distance from $x_0(d)$. In cases where these bounds are exceeded, $\delta_{pers}(d)$ experiences an exponential decay at a rate of $\tau_{pers}^{dc(d)}$, dictated by the distance from $x_0(d)$. Data losses are not tolerated in this service class; therefore, $\delta_{pers}(l)$ exponentially decreases according to $\tau_{pers}^{dc(l)}$ for any $x_0(l)$ <1.

$$\delta_{pers}(d) = \begin{cases} e^{-\frac{(x_0(d)-x_i(d))*\tau_{pers}^{in(d)}}{x_i(d)}} & x_i(d) <= x_0(d) \\ e^{-(x_i(d)-x_0(d))*\tau_{pers}^{dc(d)}} & \text{otherwise} \end{cases} \quad (7)$$

$$\delta_{pers}(l) = e^{-(x_i(l)-x_0(l))*\tau_{pers}^{dc(l)}} \quad (8)$$

The performance of the candidate networks in relation to the cost parameter, C_n, is normalised according to equation 9. Since the WAVE network has no associated cost to the user this (and any other free alternative) will always achieve the maximum score of 1. For candidate networks that exceed the maximum desired cost, $x_0(c)$, defined by the user for each category of service, the utility value exponentially decreases at a rate associated with the users willingness to pay (WTP) value.

$$C_n = \begin{cases} 1 & x_i(c) <= x_0(c) \\ e^{(x_0(c)-x_i(c))*(1-wtp)*SF} & \text{otherwise} \end{cases} \quad (9)$$

3. GRG calculation
   Once the normalised decision matrix D' has been computed, equation(2) is used to calculate the GRG for each alternative. Candidates are ranked in order and the x_i achieving the highest GRG is deemed the most suitable communication medium for ITS data dissemination.

Analysis of the GRA-based SCM is carried out through simulation, the details of which are outlined in the following section.

4 CALMnet Simulation Environment

Simulations are carried out using CALMnet, a comprehensive network-centric simulation environment, built on top of the OPNET simulation tool, for CALM-based cooperative vehicular systems [20]. UMTS has ubiquitous coverage within this environment and 10 RSUs are placed 1km apart along this roadway, acting as gateways to the network backbone.

The proposed GRA-based candidate ranking scheme is compared with two other approaches.

- Random Selection: the carrier network for the ITS application traffic is randomly selected. Safety services use broadcast communications and can be carried over any WAVE channel and UMTS. However, since the WAVE control channel (CCH) is for non-IP traffic, this is not considered as a candidate for Subscriber and Personalised services.
- Simple Matching based Selection: here, the selection requirements are simply matched with the candidate network abilities. The CCH is designed specifically to meet the need of safety applications; therefore a policy is adopted whereby safety traffic is always carried on this channel. For all other data traffic, the selection is based on simple candidate scoring. Here, all input parameters are equally weighted in importance to the overall decision and candidate scores are incremented to reflect a match with service requirements and user preferences. The candidate with the highest score is deemed the best solution.

Mobility

The open source Simulation of Urban MObility (SUMO) v0.11 package was used as the road traffic simulator to generate realistic microscopic vehicular mobility patterns. Vehicles move in each lane on the highway with varying speeds that are restricted to a maximum speed of 120km/h. The vehicle density for the simulated scenario is illustrated in Figure 1. The high density of vehicles seen at approximately 3000m is caused by the presence of a toll plaza. Here the maximum speed is capped at 50kmph resulting in a build up of vehicles in this location and thus ensuring that both free flow and congested road traffic conditions are observed.

Application Modelling

Six distinct applications are defined, the details of which are presented in Table 1. These specify their data lifetime and reliability requirements, which are used as inputs to the ranking procedure.

User preference in relation to the WTP is modelled based on data plans currently offered by mobile operators. Three categories of user are defined:

– All you can eat (AYCE)
  Users in this category have no limit on their data usage. Therefore, they are not concerned with the cost of using any ITS services; their WTP = 1 for all services.

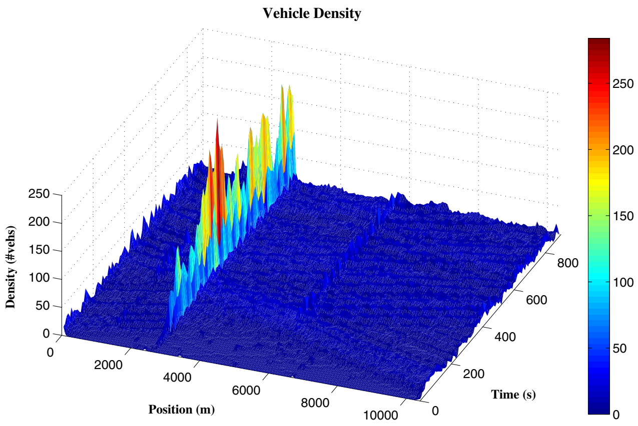

Fig. 1. Vehicle Density for simulated highway mobility scenario

Table 1. Application specifications

Service Class	Application	Communication Mode	Frequency	Data Lifetime	Reliabilty
Safety	Hazard warning	V2V Broadcast	10Hz	100ms	1.0
	Flexible lane change	V2V Broadcast	1Hz	500ms	1.0
Subscriber	Platoon	V2V	exp(45)s	15s	0.98
	TUS	V2I	exp(180)s	30s	0.95
Personalised	CVAS	V2V	-	15	1.0
	Buslane reservation	V2I	-	10	1.0

– 2GB limit
  Users on this plan have a moderate data usage plan and can afford to run ITS services. In this category the WTP ranges between [0, 0.7] for subscriber services and [0, 0.8] for personalised services.
– 200MB limit
  These users have limited data usage and will have a low WTP; between [0, 0.4] for subscriber services and [0, 0.5] for personalised services.

5 SCM Performance Analysis

Assessing the performance of the proposed SCM framework in the cooperative vehicular environment requires examination of the random, simple matching and

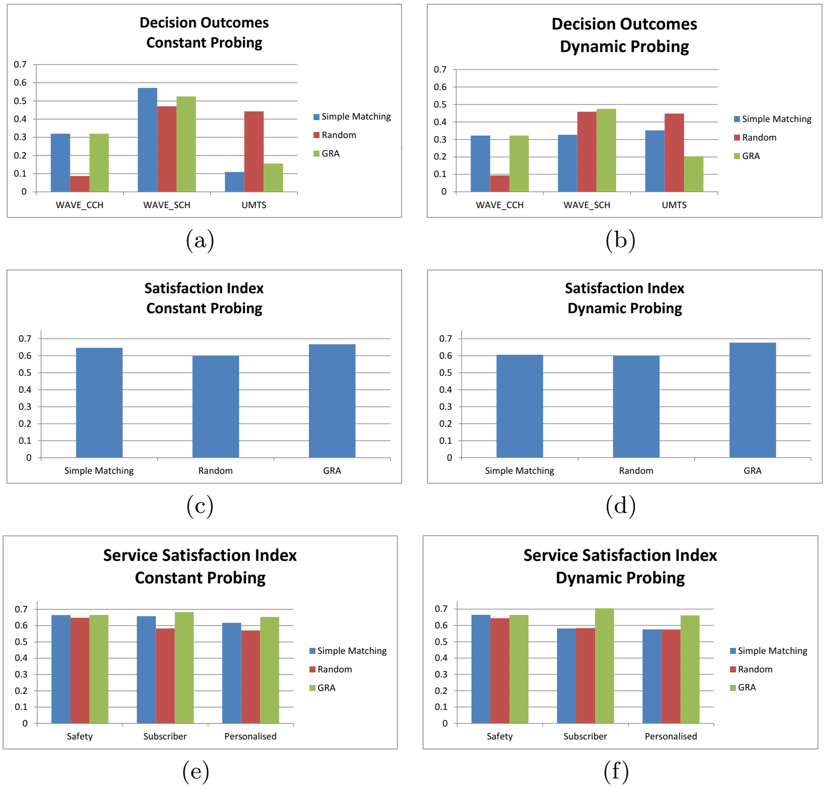

Fig. 2. Decisions and Satisfaction Index for all selection schemes

GRA based ranking algorithms as well as the two proposed monitoring methods. Two main factors are considered:

– Selection Decisions
  This gives an insight into the operation of the ranking procedure, demonstrating the choices made under the varying working conditions experienced. Figures 2(a) and 2(b) illustrate the selection decisions for each of the selection methods using both constant and dynamic probing. Here, it is evident how the network condition monitoring technique has an effect on the candidate ranking procedure with the proportions of CI selection differing for both probing schemes. As expected, the Simple Policy and GRA schemes have identical values for the WAVE CCH since all safety services are transported over this CI. Simple policy matching the WAVE SCH 57% and 33% and UMTS 10% and 35% for all decisions using constant and dynamic probing respectively. GRA has a breakdown of 52%/16% for the SCH and 47%/20% for UMTS in the constant/dynamic probing scenarios.
– Satisfaction Index (SI)
  The SI is defined as the degree to which the chosen communications network satisfies the WTP user preference and the service data lifetime and

reliability requirements. This is calculated using GRA to determine each decisions' distance from the ideally required solution. To assess the performance, equations 3 to 9 are used, with the requesting service requirements representing the reference ideal solution. The maximum grade of 1 will therefore only be achieved when exactly all requirements have been met. Referring to selections which exceed the requesting requirements will not score highly; the SI is a measure of how well the ASC objective was achieved. When examining these results, it is important to remember that the selection decision is a trade off between service requirements and user preference.

The overall SI values for each scheme is presented in Figures 2(c) and 2(d). Here, GRA-based ranking outperforms the random and simple matching selection techniques, obtaining the highest index values of 0.67 and 0.68 in constant and dynamic probing scenarios respectively. The simple matching scheme scores higher than the random selection, achieving an SI of 0.64 and 0.6. The final set of plots in 2(e) and 2(f) illustrate the breakdown of SI scores for each service category. As expected, GRA and simple matching achieve identical SI scores for safety services. For subscriber and personalised services however, GRA achieves the highest SI scores, again verifying that it is the principal ranking technique required to achieve the ASC objective.

6 Conclusions

This paper presented a framework for Service and Communication Management (SCM) in cooperative vehicular systems. Here, the goal is to ensure that ITS service requirements are met through the selection of an adequate dissemination medium from the underlying heterogeneous communication network. Specifying an objective of "Always Satisfactorily Connected" (ASC), random, simple matching and GRA-based selections are examined for both constant and dynamic probing techniques. Results show that GRA-based selection better services user and application requirements in the CALM-based cooperative vehicular environment. Constant probing proved to be the best condition monitoring technique for simple matching based selection, while the highest satisfaction index was achieved for GRA-based selection using dynamic probing.

Future work will study the affect of RSU density on the decision process; the urban scenario will also be examined. Also, the comparison of an "Always Best Connected" objective with the proposed ASC will be carried out. Additional communications technologies will also be considered.

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