Service Driven Dynamic Hashing Based Radio Resource Management for Intelligent Transport Systems

Subha P. Eswaran[1], Jyotsna Bapat[1], and V. Ariharan [2]

[1]International Institute of Information Technology, Bengaluru, India
subhape@bel.co.in, jbapat@iiitb.ac.in
[2]Central Research Laboratory, Bharat Electronics Limited, Bengaluru, India
ariharanv@bel.co.in

Abstract. Intelligent Transport Systems (ITS) aim to improve transport safety, productivity and reliability by interconnecting different transport entities and providing real-time instantaneous transport information to various transport system users. Communication systems play an important role in achieving this mission. Heterogeneous technologies/protocols such as WLAN, DSRC, RFID, GSM, WiMAX etc. currently constitute the communication system of ITS. ITS comprises of various services (monitoring, navigation, value-added services etc.) with diverse Quality of Service (QoS), latency & throughput requirements. Large number of aperiodic and sporadic service requests from heterogeneous radio communication devices are expected to result in another type of congestion; the spectral congestion. In this paper, we propose an efficient radio resource management scheme using Complex Event Processing (CEP) based Service-Prioritized Opportunistic Communication (SPOC) architecture to address this spectral congestion. Based on CEP, SPOC processes the simple events such as information about spectrum usage patterns, radio device abilities, geo-locations, spectrum needs and derives complex spectrum allocation decisions. Spectrum allocation and management decisions are governed by policy engine of SPOC. Volume of spectrum request is predicted by Time of the Day based Dynamic Hashing algorithm that reduces computation complexities and achieves faster spectrum allocation decision. This infrastructure based spectrum management technique is shown to improve service completion rate for all devices while satisfying dynamic QoS needs of emergency/high priority services of ITS. Compared to existing scheduling schemes such as Greedy, Max-Min and Early Dead-Line First algorithms, SPOC is shown to be more suitable for ITS paradigm due to its ability to coordinate several hundreds of spectrum demands in real-time, while maintaining fairness.

Keywords: ITS, CEP, Dynamic Hashing, Spectrum Management.

1 Introduction

Intelligent Transport Systems (ITS) can be defined as the application of advanced Information & Communication Technology (ICT) to vehicles and infrastructures in order to achieve enhanced safety and mobility while reducing the environmental impacts of transportation [1]. The vision of ITS is accomplished by means of information exchange

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among many diverse ITS entities from road side communication infrastructures (traffic signals, sensors, message boards), transportation and management systems, to the end users - their vehicles. The information exchange in ITS should be capable of detecting and reporting various traffic events in real time and should generate useful, reliable and instantaneous traffic information to support the travelers, freight managers, system operators and other transport system users.

Communication technology entities of ITS encompass fixed devices and mobile devices fitted to vehicles and other moving objects [2]. On-board vehicle devices should have the instantaneous information exchange through which speed and nearness of the surrounded vehicles can be sensed and act accordingly to have an accident free drive. Within the vehicle there may be devices that communicate with the infrastructure entities to get traffic updates that help to avoid traffic jam or to avoid foggy and slippery roads which need to happen on the move. Some on-board devices need to communicate with infrastructure entities such as Road Side Units (RSU), message boards to get route update, map download, toll or parking information. ITS can be visualized as a coordinated and co-operative real-time information system composite of various time bounded data exchange at different service level criticalities such as ambulance, police, incident-driven, monitoring, warning and alarm services. Different services of ITS have different latency & throughput requirements and require different communication channel access requirements. For example, emergency services like incident response requires high priority channel access with less data throughput whereas data base services like route-map download requires more data throughput but low priority can be given for accessing the channel. If the spectrum sharing is not coordinated it may lead to a situation that emergency information exchanges could starve of channel congestion while high bandwidth demanding low-priority applications such as media-download occupies the channel. This requires a service driven QoS policy based spectrum sharing mechanism for future ITS.

If all ITS communication systems were to use same communication standard, it would have been easy to achieve shared communication access. But currently information exchange for ITS takes place through various forms of communication technologies (GSM, WLAN, etc.) constituting a heterogeneous network scenario. Heterogeneous communication technologies must act cooperatively to provide various services for ITS. It is also worth noting that different services of ITS demands different Quality-of-Service, end-to-end delays and bandwidth requirements [3]. In addition each ITS entity will experience different wireless channel state conditions depending upon their mobility or geo-locations. However since different ITS entities need to share the same spectral bandwidth there is a need to define spectrum sharing mechanism for ITS depending upon the services offered and channel conditions to meet the QoS requirements.

The challenges associated with the spectrum management of ITS are very close to the concerns seen in that of heterogeneous networks (HetNets) [4, 5, 6] listed in table 1. Compared to Home-Net or Health-Net scenario ITS must deal with rapidly changing complex scenario with large number of players. In addition, mobile scenario requires quick spectrum decisions compared to other HetNets and low computation capacity of the participating devices limits the use of complex distributive spectrum management solutions. This mandates the need for a centralized opportunistic spectrum management solutions for ITS. Considering these requirements, Service Prioritized Opportunistic Communication (SPOC) architecture is proposed in this paper. Our contributions are in three fold:

- Service type classification and Complex Event Processing (CEP) Engine based Service driven communication architecture proposed for ITS.
- Time of the Day (ToD) based Dynamic Hashing methodology is introduced to map the spectrum demands and spectrum availability.
- Service driven spectrum sharing algorithm based on service priorities, time-criticalities and QoS.

The rest of the paper is organized as follows: Related works are presented in Section-2. System model of SPOC-ITS is described in Section-3. Dynamic hashing and Service driven spectrum sharing algorithm are detailed in Section-4. CEP based prototype implementation and performance comparisons with Greedy/EDF/Max-Min are presented in Section-5. Conclusions and future work can be found in Section-6.

Table 1. Comparison of Heterogeneous networks

Sl. No.	Parameter	ITS	Home Net	Health Network	Cognitive Radio Network
1	Heterogeneous Technologies GSM, WiFi etc.	√	√	√	√
2	High Density of nodes/sq.km >500	√	X	X	X
3	Various service Priorities	√	X	X	X
4	Mixed & multiple time critical (Ambulance, police, fire, VIP) nodes	√	X	√	X
5	Power constraints/low battery device	√	X	X	X
6	Almost 80% of device has low capacity	√	X	Partial X	X
7	Rapid Radio environment/Channel state variation due to mobility	√	X	X	X
8	User Mobility (high speed vehicles)	√	X	X	√

2 Related Work

Centralized spectrum allocation schemes for Multi-Radio Access Technology environment and for Cognitive Radio Network is introduced in [7, 8] have high latency and not scalable; making them unsuitable for ITS, where several hundreds of requests must be processed per second. Centralized solutions provided for cellular networks [9] are not suitable for ITS either, as they don't consider the service priorities or the time criticality of the spectrum needs.

Spectrum resource allocation problem is similar to any resource allocation problem and well established algorithms such as Max-Min/Back Pressure, Greedy, and Early Dead Function (EDF) can be applied. Each algorithm has its pros and cons such as

Greedy algorithm provides high throughput, but lacks in fair scheduling [10], while Max-Min Fair algorithm [11] achieves fairness at average throughput and critical jobs are not prioritized. To manage time critical jobs, EDF/mixed-critical algorithms [12] can be considered. While employing these methods time critical jobs will get served but achieves average throughput. In [13], EDF/FIFO based spectrum scheduling for voice and data processing of ITS is introduced that satisfies the QoS needs but there is no provision of improving spectrum utilization or fairness and it lacks in scalability. In [14], vehicle-mounted communication gateway for ITS is presented, for managing the on-board communication with the back-office, which doesn't include other entities like road-side infrastructures and other sensor communications. New spectrum management architecture is essential for ITS that can satisfy diverse latency needs, QoS requirements, time criticality and multiple service priorities of various entities of ITS network, while managing the multitudinous spectrum demands in a fairway. One such architecture is proposed in this paper.

3 System Model

3.1 Proposed Architectural Framework of SPOC

The architecture of the Service Prioritized Opportunistic Communication (SPOC) for ITS is depicted in Fig. 1. SPOC kind of architecture is used for spectrum management of IoT proposed in [15].The functional modules of the proposed system are described below.

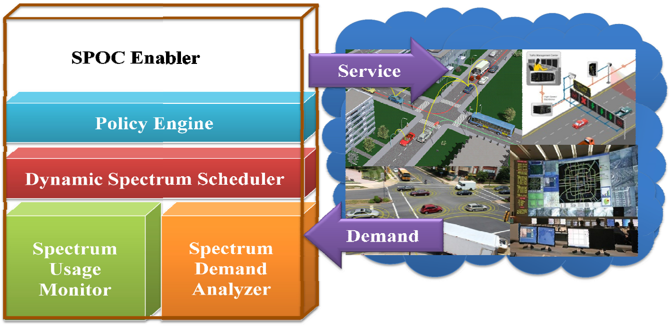

Fig. 1. SPOC architecture

- Spectrum Usage Monitor: It has spectrum sensing and interference analysis module. Information about spectrum availability of different frequency bands and their interference measures are archived by these modules. A location awareness module is used to enforce the geo-location based rules for spectrum sharing.
- Spectrum Demand Analyzer: Collects the spectrum demands from various players. It classifies the type of service requested and analyzes the capacities of the devices like protocol supported, latency limits and operable frequencies.

- Policy Engine: Has a set of spectrum allocation rules based on the operating spectrum band, type of service, type of player and device capabilities. These rules are dynamic depending upon geo-locations subject to local policies.
- Dynamic Spectrum Scheduler (DSS): The DSS makes spectrum allocation decisions in conform to the conditions of the Policy engine.

3.2 Deployment Overview of SPOC

The area of the city under ITS can be partitioned into multiple zones, based on the coverage area of the central entity. SPOC will be located in every zone that facilities the spectrum demand needs of ITS. Radio devices in each ITS zone are categorized into three major group of players: (a) Static communication devices placed across the entire zone; (b) Mobile nodes (pass by vehicles) which enter into the zone and move around the zone for limited time; (c) Moderator nodes (interceptors) which are semi-mobile and move within the zone and stays in the zone for long time (few hours). Every radio device that enters SPOC zone will be given spectrum suggestions as per the sequence flow depicted in Fig. 2.

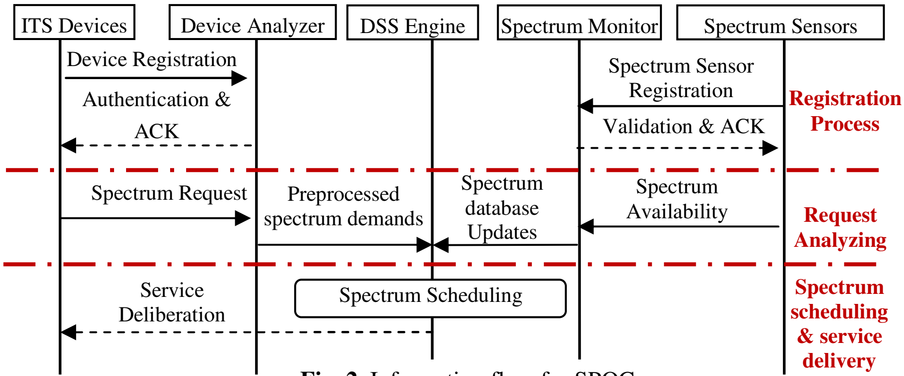

Fig. 2. Information flow for SPOC

3.3 Proposed Service Classification of SPOC

Table 2. Proposed Service Classification of ITS

Type of Service	Characteristics	ITS application
Type-I - (database service)	Lowest priority/more spectrum usage time & high bandwidth > 1Mbps	Map / Media downloading, Field Vehicles, Static Infrastructures
Type-II- (Environment aware service)	Low spectrum usage time and low bandwidth <1Mbps	Inter-vehicle communication, parking and toll functionalities
Type-III - (alarm & warning service)	Low spectrum usage time and low bandwidth <100Kbps	Traffic jam/ weather warnings
Type-IV-(Incident driven services)	Highest priority / less spectrum usage time and low bandwidth <50Kbps	Ambulance/ Emergency vehicle/ road accident notification

4 System Design

Spectrum decisions are processed by DSS in three phases as given below:

Phase 1: Dynamic Hashing. Time of the Day based Dynamic Hashing technique is introduced to categorize the requests based on bandwidth demands. Each bandwidth bucket is applied with second level hashing to obtain service classified buckets.

Phase 2: Prioritized Scheduling. Service classified buckets are enforced with prioritized scheduling scheme dictated from policy engine. As the scheduling algorithm is applied separately on different service buckets and not on the large set of requests, it reduces the spectrum decision making time.

Phase 3: Spectrum Mapping. Available Spectrum dataset is hashed with ToD based dynamic hashing using bandwidth as key. Prioritized scheduled requests of different service buckets will be mapped to the spectrum availability buckets.

4.1 Dynamic Hashing

The main idea of hashing is to divide the dataset 'B' into a number of 'N' disjoint subsets or buckets B_1, B_2,..B_N. They are useful for lookup of information since the hash indexing makes the process very efficient. In ITS, it can be noted that the requested bandwidth varies from minimum of few Kbps (alerts/warnings) to maximum of few Gbps (video surveillance/media download) [2]; accordingly it is proposed to have a hashing function that categorizes the large set of spectrum demands to smaller subsets based on requested bandwidth. By hashing the spectrum demands based on requested bandwidth, it will form 'N' different bandwidth buckets. Each bucket represents a certain range of bandwidth say bucket '1' (B_1) can have spectrum demands that falls between 1k to 10kbps and bucket '2'(B_2) will have requests range from 20k to 100kbps and so on. Static hashing assumes a static number of buckets and static bucket size. However the dynamic scenario in ITS demands, variable bucket size and variable bucket numbers, i.e. dynamic hashing.

Dynamic hashing offers the flexibility of variable bucket number/size by the concept of extendable bucket or bucket spilt methods. Dynamic hashing suffers the problem of bucket re-assignment even for a small flow change which is unnecessary and increases computation burden [16]. So if the volume of requests for a bucket can be predictable, re-assignment of buckets can be done in a more efficient manner. In ITS the interesting factor is that the spectrum demand is in general proportional to the vehicle traffic. And also vehicle traffic varies according to the Time of the Day (ToD). It is also understood that as the traffic is low, the bucket numbers/size can be reduced and as the traffic is high it can be increased. Dynamic hashing with flow volume is introduced in [17], for managing data traffic in Internet where flow volume is determined using best-flow and largest-flow fit algorithms. In this paper, ToD based dynamic hashing is introduced exclusively for ITS spectrum management.

First Level Bandwidth Hashing - ToD Based Dynamic Hashing. Hash function is chosen to map the incoming spectrum demands into bandwidth buckets B_1, B_2,…B_N. Hash value is generated as following :

→ Hash value: H(bandwidth, duration of usage) mod K

→ K= N - number of bandwidth buckets.

The number of buckets and their size can be decided dynamically depending upon the incoming volume of the spectrum demand requests. Generally the bucket re-assignment is determined by policy. Here Time of the Day based policy set is adopted. Accordingly, three hash functions (H_H, H_M, H_L) are used to give three different bucket re-assignment strategies. H_H is applied at the Time of the Day when there will be heavy road vehicle traffic. H_L represents the scenario where spectrum demand requests are sporadic and minimal for most of the buckets. H_L is assumed to occur at the Time of the Day when there will be low road vehicle traffic. H_M is a moderate scenario of H_L and H_H. For the H_L and H_M cases, the number of buckets will be less than H_H. Bucket assignment of ToD based dynamic hashing is shown in Fig.3.

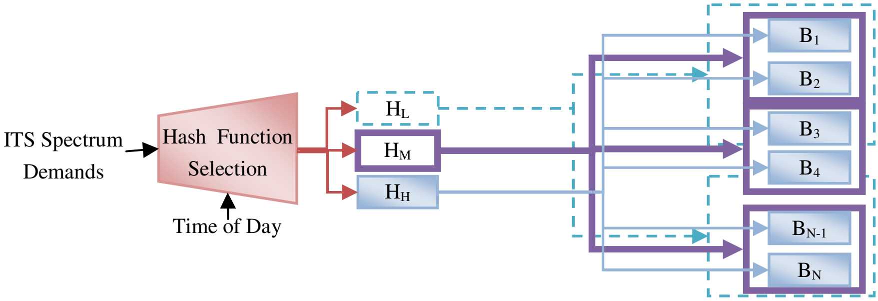

Fig. 3. ToD based Dynamic Hashing

Second Level Service Hashing-Static. Following the bandwidth dynamic hashing, a second level static hashing is carried to sub categorizes the bandwidth buckets. The second level hashing divides each bandwidth buckets into four service buckets according to class of service as discussed in section-3.3. Accordingly, four service buckets (S_1B_i, S_2B_i, S_3B_i, S_4B_i) for each bandwidth hash bucket (B_i) is obtained; i varies from 1,2,…N. Each bandwidth requests are scheduled depending upon the latency, QoS and device capacity which is described in the following section. Prioritized requests will be mapped to the requested bandwidth of the available spectrum. The flow of hashing, scheduling and mapping to the available spectrum is illustrated in Fig. 4 that depicts the functional overview of the spectrum decision framework of DSS.

4.2 Prioritized Scheduling Algorithm

Policy engine of SPOC calculates the service priority of 'i^{th}' spectrum demand, requesting class 'j' service of 'k' type player according to the following expression

$$S(i,j,k) = e^{\delta_j \Omega_{jk}} \times \left(\gamma_j \times \left[\frac{q_i(t)}{M_i}\right]\right) \quad (1)$$

where δ_j is the fairness coefficient, γ_j is the value assignedas per the service type (shown in Table 3), Ω_{jk} is the balancing factor for player type 'k' of the traffic class 'j', M_i is the tolerable latency measure of request 'i', $q_i(t)$ is the queuing time of the spectrum demand request 'i' since its arrival until being served at time t. The priority function in equation (1) has three parts; latency term, fairness term and player term.

Latency Term (q/M): The demands whose queuing time is nearing its maximum delay limit will be served at high priority. Type-4 is given high gain factor (γ_j).

Fairness Term (δ_j): Fairness is ensured by δ_j term. $\delta_j = \frac{n_j}{N}$, where n_j is the total number of service demands waiting for j^{th} service type and N is the sum of service demands in all type of services. As n_j increases the chances of getting served also will increase and hence maintain the fairness.

Player Term (Ω_{jk}): It helps to assign additional preferences based on the type of players (vigilant/VIP vehicles) in ITS. The priority order of ITS players and their weight allocations are shown in Table-4.

This priority calculation is applied on the service buckets of each bandwidth hash buckets separately that forms prioritized FIFO queue as shown in Fig.4.

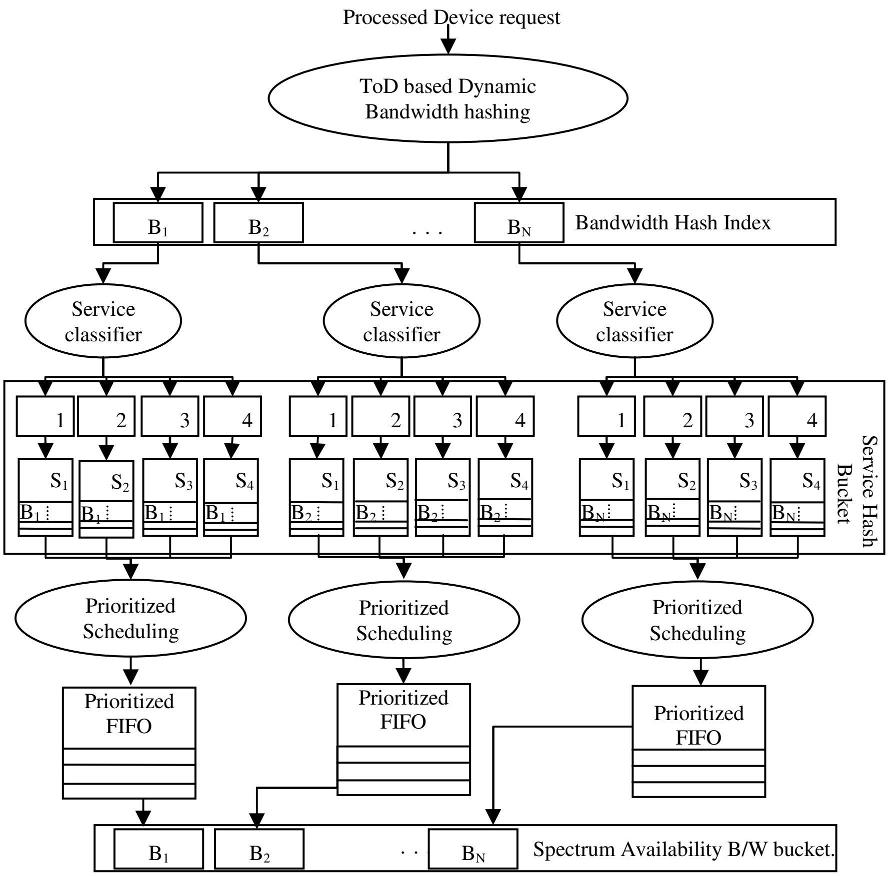

Fig. 4. Functional Flow of Spectrum Decision framework of DSS

Table 3. Service Type Prioritization

Service Type	Priority Order	γ_j
TYPE –I	1 (Lowest)	0.2
TYPE -II	2	0.4
TYPE -III	3	0.6
TYPE -IV	4 (Highest)	0.8

Table 4. ITS player Prioritization

ITS Players	Priority (Ω)
Emergency/VIP Vehicles	1.7
Interceptors	1.6
Alarm service (VMS/HAR)	1.5
Vehicles (route requester)	1.4
Field Vehicles	1.3
Static Infrastructures	1.2
Commercial Vehicles	1.1

5 Prototype Implementation and Performance Measures

The proposed SPOC architecture is implemented in Complex Event Processing (CEP) engine. In practice, a CEP engine is used to aggregate simple events and derive a complex decision from it. CEP provides intelligence into event-driven systems by deriving higher-level knowledge from vast amount of lower-level data [18]. Spectrum decision framework for ITS is visualized as event-driven system and hence CEP is chosen to implement the same. One of the advantages of using CEP for SPOC is that it can serve hundreds of events per second with minimal latency. SPOC is implemented in JAVA 1.7 and Esper 5.0.0. SPOC and spectrum demand events from ITS scenario are simulated with two different machines having the configurations of: Intel core i3 – 2120 @ 3.3 GHz processor with 4GB RAM running Windows 7 OS.

Simulated spectrum demands are passed to SPOC using UDP socket. A packet handler at SPOC captures spectrum demand as Plain Old Java Object (POJO) and passes it to Esper engine for event processing.

5.1 Performance Measures

SPOC performance is compared with the three algorithms (Greedy, Max-Min, EDF) implemented with JAVA 1.7 and MySQL Server 5.0. MySQL is an Event Stream Processing (ESP) tool based on Structured Querying Language (SQL) that processes the homogenous data streams whereas CEP can handle heterogeneous data streams. The performance measures for comparison are listed below.

Spectrum Utilization: It is a measure for utilization of available spectrum among the requesting players such that spectrum wastage is avoided or minimal. Assuming constant spectrum availability at the start of simulation and increasing spectrum demands, percentage of spectrum utilization is calculated for EDF, Max-Min, Greedy and SPOC. Spectrum utilization improvement depends upon efficiently mapping the requirements of spectrum demand (in terms of requested bandwidth, usage time, tolerable latency) with the characteristics of available spectrum band (in terms of interference, bandwidth and idle time) and number of request served. Greedy algorithm does the mapping based on bandwidth while Max-min algorithm maps based on serving many demands and EDF allocates to highest latency prone requests. Whereas the proposed algorithm considers usage time, idle time, bandwidth, latency and type of service and achieves improved spectrum utilization factor than other three algorithms, as shown in Fig.5.

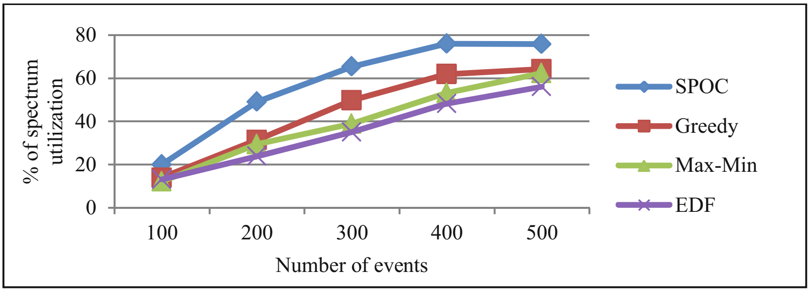

Fig. 5. Spectrum Utilization Comparison

Fairness Measure (impact of δ term): The special feature of the SPOC system is that in spite of the priority based servicing, it maintains fairness among all types of services. It can be observed from Fig. 6 that SPOC offers almost equal service completion ratio (for 500 uniformly distributed events of all types of service) whereas greedy and EDF fails to achieve fairness. It also out performs Max-Min.

Servicing – Rate of emergency request: Type-IV events are highly time-critical events having deadline in terms of few milliseconds, failing which they will get discarded. As the demands of such requests increases, meeting the time constraints of all such events will be not possible leading to service blocking. The service percentage of Type-IV demands is taken as a measure to evaluate the algorithms shown in Fig.7.

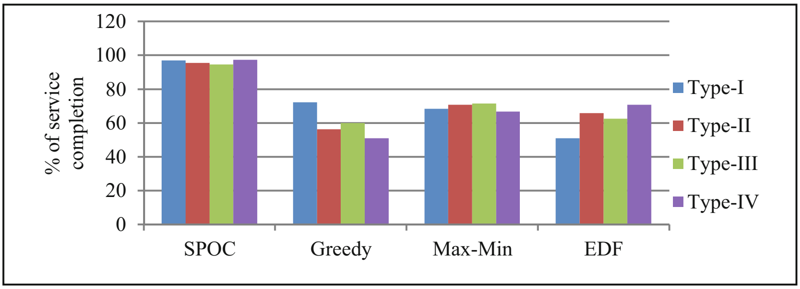

Fig. 6. Fairness Measure Comparison

5.2 Observations and Discussion

Hashing reduces the number of search in mapping ‘m’ bandwidths to ‘n’ demands. The referenced algorithms (Greedy/EDF/Max-Min), for every spectrum allocation, all ‘m’ resources and ‘n’ requests have to be processed and compared to derive the best solution that leads to $m \times n$ computations. Whereas with hashing mechanism, search is limited by the number of buckets (N) that reduces the input space by explicitly eliminating known mismatches. Hence computation complexity is approximately equivalent to $\frac{m \times n}{N^2}$. When the number of bucket is approximately equal to $\frac{n}{\log n}$, the computation is as minimal as $max(log\, m\, , log\, n)$. Along with this, the use of CEP significantly improves the service time than SQL based implementation. The events serving percentage of the referenced algorithms in comparison with SPOC is shown in Table 5.

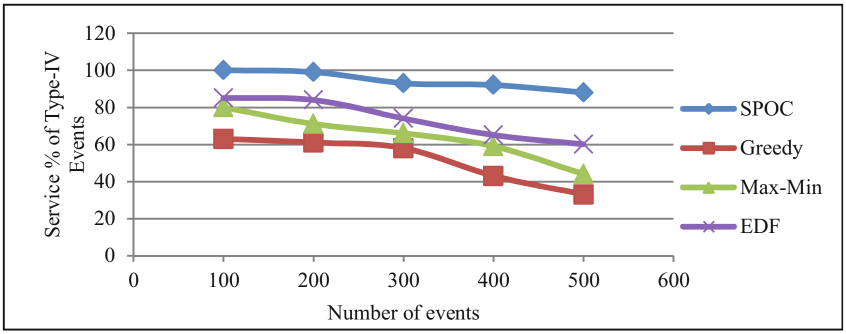

Fig. 7. Emergency – Requests Serving Rate Comparison

At heavy traffic, SPOC could accommodate many requests as compared to other algorithms as noted from table 5. From Fig. 5 to 7, it can be observed that Greedy offers better spectrum utilization but fails to handle emergency cases. EDF may perform better for handling emergency service but fails to offer fairness and spectrum utilization. Max-Min offers fairness but throughput is less compared to SPOC. Proposed algorithm achieves all the three measures while reducing number of computations using hashing. In addition CEP based proposed solutions can handle hundreds of requests per second providing real-time services.

Table 5. Servicing percentage of various algorithms compared with SPOC

Traffic Type	Service demands (all types)	SPOC	EDF	Max-Min	Greedy
Peak (H_H)	1200	1078 (89.8%)	607 (50%)	634 (53%)	598 (49%)
Medium(H_M)	670	639 (95.5%)	398 (59%)	404 (60%)	386 (57%)
Low(H_L)	300	300(100%)	211 (70%)	228 (76%)	224 (74%)

6 Conclusions

In this paper, zone-based service-driven opportunistic communication enabler has been proposed for ITS which consists of Dynamic Spectrum Scheduler (DSS) and policy engine. Based on the current spectrum occupancy, type of spectrum demands from ITS players and the capabilities of the radio devices, DSS allocates the spectrum in real time. The policy engine considers the different functional requirements of ITS objects while deciding the priorities for spectrum access. Time of the Day based Dynamic Hashing is introduced to handle the dynamic volume of spectrum demands and reduce computation complexities. The advantages of ITS-SPOC enabler are that it is flexible, adaptive and has low service denials. It can support multitude service demands with improved spectrum utilization as compared to well established scheduling algorithms such as Greedy, Max-Min or Early Dead-Line First. Dynamic nature of SPOC allows it to adopt varying priority measures to match with the different city traffic needs. SPOC enabler can act as a gateway for ITS-communication system to support instantaneous real-time traffic information exchange which is the prerequisite to manage the city-wide traffic efficiently. Security measures for SPOC will be considered for future scope of the work.

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