Dynamic Small cell Management for Connected Cars Communications

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***Abstract*—In this paper, we present the Dynamic Small cell Management (DSM) scheme to improve vehicular communications, focusing on the dynamic allocation of small cells when the macrocells cannot cope with the traffic generated by the connected cars. We have considered real base station deployments in the city of Dublin, Ireland, combined with realistic models of vehicle mobility, and small cell deployments. Simulation results demonstrate that our DSM scheme improves communication capabilities (the number of messages correctly received by the infrastructure increases up to a 43.75%), while it also reduces BS overloading (the number of messages managed by the base stations is reduced up to an 8.72%). Therefore, the use of this smart and dynamic solution not only benefits vehicles' communications but also mobile operators.**

***Index Terms*—network intelligence, resource allocation, dynamic composition, vehicular networks, small cells, offloading**

I. Introduction

The upcoming communications networks, the so-called 5G future networks, feature different heterogeneous network technologies working in a unified, seamless, and converged manner, proving a space of connectivity solutions. Such solution space, allows operators to dynamically tailor their networks to the services demanded by end-users.

5G technologies will empower vertical sectors such eHealth, Smartgrid, IoT, Smartcities, and Smart mobility, among others. Within the myriad technologies that are part of 5G solutions, the coexistence of 3G/4G networks with Small cells (SCs), including Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE), and Wireless Fidelity (Wi-Fi) access technologies [1], is undoubtedly one key solution to provide solutions capable to cope with the continuously variable demand of mobile users, including vehicular communications, and to dynamically re-arrange the mobile networks [2].

Connected vehicles and its wide spectrum of applications, such as cooperative collision warning, improved rescue, road obstacle detection, weather information, video streaming, and music download, require continuous connectivity with different type of service levels, varying from low latencies connections to huge amount of broadband capacity, in particular when referring to future autonomous vehicles. Traditional mobile networks, sometimes are not capable to fulfill such unforeseen demand. However, with a base station deployment and the dynamic allocation of small cells, we can shift resources and capacity to any location where they are needed it.

In this paper, we present a solution focused on the dynamic allocation and management of small cells when the macrocells cannot cope with the traffic generated by the connected cars. We have considered real Base station (BS) deployments in the city of Dublin, Ireland, combined with realistic models of vehicle mobility, and small cell deployments. Our results demonstrate how much the connected cars benefit from the use of SCs, and how much the Mobile Network Operators (MNOs) also benefit from such smart and dynamic solution in terms of traffic offloaded.

II. Related Work

Heterogeneous networks (HetNets) role can be seen as a cost effective way to deal with the increasing data traffic demand, especially in Vehicular Networks. HetNets can include a combination of macrocells, small cells, picocells, and femtocells, always focusing on increasing the capacity of the network in terms of coverage and capacity while offloading traffic from macrocells.

Regarding the use of both macrocells and microcells to improve the overall performance, Li et al. [3] study the coexistence of LTE and Wi-Fi technologies in the same unlicensed band while avoiding severe interference between them. Tran et al. [4] present a future C-RAN based cloud cooperated HetNet which enables global resource optimization among small cells. The architecture allows optimal user association for data offloading as well as dynamic ON/OFF of small cells in adaptation to daily data traffic.

Some authors have presented novel solutions when deploying small cells. Mozaffari et al. [5] propose the use of drone small cells (DSCs) which are aerial wireless base stations that can be mounted on flying devices such as unmanned aerial vehicles (UAVs). Specifically, authors propose an efficient deployment of such DSCs while optimizing the covered area. Similarly, Li and Han [6] provide high-data-rate transmission in poor coverage areas, utilizing UAVs.

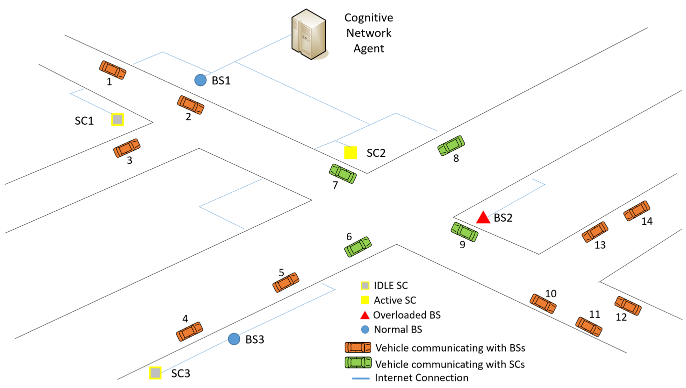


Fig. 1: DSM scheme - Working mode example.

In heterogeneous networks, another important matter to account for is continuous connectivity. Therefore, advanced handover techniques have been widely studied. In particular, a set of techniques to seamlessly and transparently [7] offer connectivity to users anywhere and anytime is required. In the vehicular context, Marquez-Barja et al. [8], [9] proposed an enhanced algorithm empowered by the IEEE P802.21 standard that enables seamless vertical handovers among heterogeneous access technologies such as Wi-Fi, Worldwide interoperability for Microwave Access (WiMAX) and UMTS.

To the best of our knowledge, most proposals are focused on very specific and simple scenarios which cannot be easily extrapolated to Vehicular Networks. In our work, we have developed a system designed to handle high data traffic demand vehicular environments. Additionally, we have considered real mobile operator BS deployments in a real city, combined with realistic models of vehicular mobility.

III. Dynamic Small cell Management

In order to avoid the overloading of BSs, within crowded vehicular contexts, we propose an architecture that combines BSs and SCs. The activation and deactivation of SCs is managed by the Cognitive Network Agent (CNA) entity. We consider that the CNA, based on the IEEE 802.21 Information Service, is able to connect and retrieve up to date information from Small cells and Base stations. Such information includes network status, load, features, and pricing, among others.

The main philosophy behind our proposal, is that the network architecture, due to the collaborative scheme based on the IEEE P802.21 standard, is capable to balance the load of the entire network by offloading overloaded BSs with the smart activation of SCs whenever it is required. We envision connected cars, in particular future autonomous vehicles, stressing mobile networks out by dumping huge amount of data to the cloud to be timely processed. That requires that the mobile network can deliver low latency and broadband services in a reliable manner. Figure 1 presents an example of the working mode of our proposed architecture. Depicted orange cars represent the vehicles that are using 3G communications, (i.e., they send their messages to a Base station (BS)) and green cars represent those which are sending the information through Small cells (SCs). In the top-left corner, vehicles 1 to 3 send the information through BS1, which is able to manage all the information received, making unnecessary the activation of SC1 by the CNA. In the right part of the figure, BS2 cannot manage all the messages that nearby vehicles (i.e., vehicles 7-12) are sending. However, using our proposed architecture, the CNA detects this situation, marks BS2 as ”OVERLOADED”, and informs all these vehicles about an alternative infrastructure element (SC2 in this case). Since vehicles 7-9 are able to connect directly with SC2, they redirect their traffic, using the IEEE 802.21 Command Service, thus reducing the amount of information sent through BS2. Note that vehicles 10-14 also received the suggestion of changing their interface, but as none of them are able to connect with SC2, they keep sending their messages though BS2. Note that once SC2 has been activated, although vehicle 5 would be able to connect to it, since BS3 is not overloaded the CNA does not suggest this vehicle to change its interface, so the vehicle keeps sending the information through BS3.

Listing 1 shows the pseudo-code of the algorithm implemented in the Cognitive Network Agent (CNA). As shown, it monitors the BSs in order to detect when a BS is getting overloaded, finding the closest SC, activating it, notifying the Base Station its alternative, and setting the ”OVERLOADED” mode in this BS.

Listing 1: CNA algorithm

```
//CNA algorithm

while (1) do
 foreach BS do
   if (BS[i].usage > usageThreshold) then
        BS[i].setMode("OVERLOADED");
        alternativeInterface =
             findClosestAlternativeTo(BS[i]);
        alternativeInterface.activate();
      BS[i].notify(alternativeInterface);
   end if;
 done
done
```

Listing 2 shows the code executed in each BS when it is marked as ”OVERLOADED”. As shown, the BS suggests to every connected vehicle the new interface proposed by the CNA, trying to reduce the amount of information received, and thus mitigating the traffic congestion.

Listing 2: Base Station algorithm

```
//Base Station Algorithm

while (1) do
 if(mode == "OVERLOADED") then
     foreach connectedVehicle do
        vehicle[i].newInterfaceSuggestion(
                             alternativeInterface);
     done
 end if;
done
```

Finally, Listing 3 presents the pseudo-code of the algorithm included in each vehicle. When a vehicle receives the suggestion to change its interface, it checks the possibility to connect with the proposed SC, if so, it changes the interface before sending a new message.

Listing 3: Vehicle algorithm

```
//Vehicle Algorithm -> newInterfaceSuggestion

while (1) do
 if (newInterfaceSuggested) then
    if (testConnection(alternativeInterface))
       then
         sendMessageThrough(alternativeInterface)
     else
         sendMessageThrough(lastInterfaceUsed)
     end if
 end if
done
```

IV. Simulation Environment

We studied, through simulations, a real 3G infrastructure deployment from an Irish network operator. We also considered that Small cells, based on the IEEE 802.11p standard, are also deployed following a Geographic approach [10]. They remain dormant and can be activated by the Cognitive Network Agent to alleviate the traffic congestion in BSs while increasing the communication capabilities of the vehicles.

We run simulations using the ns-2 simulator [11], which was modified to simulate 3G BSs, as well as Wi-Fi-based SCs, using the IEEE 802.11p. We also enhanced the simulator by making use of the Real Attenuation and Visibility (RAV) propagation model [12], which increases the level of realism of the vehicular context by accounting for real urban roadmaps and obstacles that have a strong influence on the wireless signal propagation (in particular within the 5.9GHz band). Regarding the mobility of vehicles, our model mimics the movement of vehicles in the city of Dublin. Specifically, we used the CityMob for Roadmaps (C4R)[1], a realistic traffic generator software based on SUMO [13]. Regarding data traffic, we considered data-intensive applications in the vehicular environment. In particular, we simulated that vehicles send high amounts of data to a Traffic Control Center (TCC) at a speed of 1 MB/s (e.g., all data acquired by the built-in sensors currently available in vehicles), and vehicles can communicate with both the 3G BSs and the 802.11p SCs. As for the vehicle density, we simulated 500 vehicles traveling in the scenario and all of them send data gathered by their sensors to the TCC. Particularly, we compared the performance of two different scenarios in this study: (i) a Traditional Infrastructure-based communications, where all the vehicles send their data packets through the available 3G BSs, and (ii) a Dynamic Small cells within vehicular context, where the CNA can dynamically activate additional infrastructure elements on demand to increase the vehicles' communication capabilities when network traffic congestion is detected. The parameter setting is summarized in Table I.

[1] C4R is freely available at http://www.grc.upv.es/software/

TABLE I: Parameter setting for the simulation.

Network-related parameters	
number of BSs	10
maximum number of SCs	25
BSs locations	real Mobile Operator GPS coords.
SCs locations	Geographic deployment [10]
BSs Propagation model	FreeSpace
SCs Propagation model	RAV [12]
BSs frequency	2.1 GHz
SCs frequency	5.9 Ghz
message size	1024 Bytes
message rate	1000 per second
Mobility modeling	
number of vehicles	500
roadmap layout	Dublin
simulated area	$5km^2$
mobility model	Krauss [14]
maximum acceleration of vehicles	1.4 m/s^2
maximum deceleration of vehicles	2.0 m/s^2
driver reaction time (τ)	1 s

V. Evaluation

In this section, we assess the performance of the Dynamic Small cell Management (DSM) approach in terms of overloading mitigation and communications efficiency among vehicles and the TCC. In this study, the metrics studied are:

- *Overload reduction.* This metric measures the effect of activating SCs in terms of percentage of use of the BSs. It also provides information about how much the Mobile Network Operators benefit from such smart and dynamic solution in terms of traffic offloaded.
- *Messages received.* This metric calculates the number of messages sent by vehicles which are successfully received by the infrastructure elements (i.e., BS and SC). It allows us to determine how much the connected cars also benefit from the use of SCs in the vehicular environment.

To properly validate the performance of our DSM scheme, we have analyzed the number of messages received by both BSs and SCs under the two aforementioned scenarios (i.e., Traditional and DSM) in four 30-seconds different periods along a 120s simulation, i.e., 0-30, 30-60, 60-90, and 90-120 seconds.

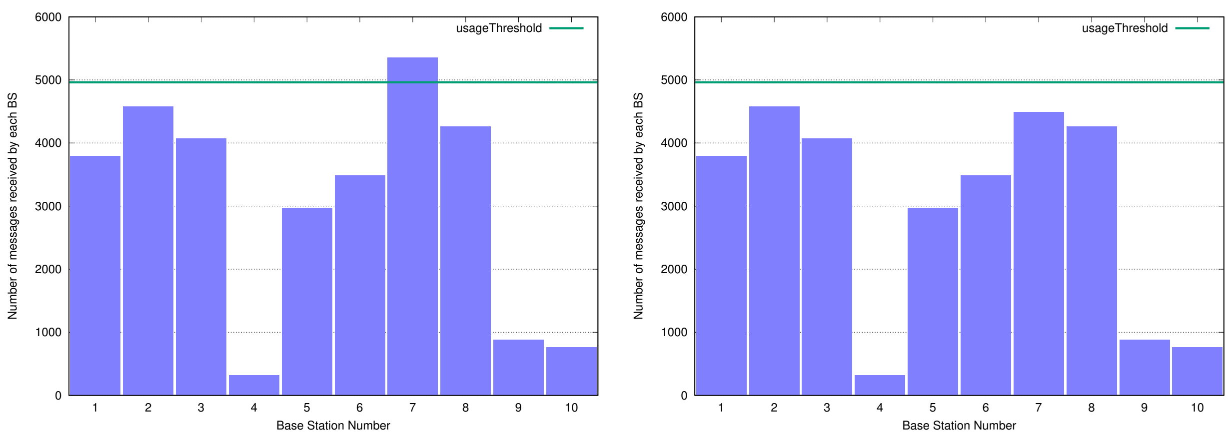
Figure 2a shows the Dublin layout highlighting those BSs that present a load rate higher that 80% (the UsageThreshold considered by DSM). As shown, using the Traditional approach (where vehicles only communicate with BSs) the BS close to Dolphins Barn area presents an overload situation. According to our approach, (i) the CNA detects this situation, (ii) activates the closest SC, and (iii) redirects all the messages sent by the vehicles that are able to communicate with this SC (see Figure 2b).

Figure 3 presents the number of messages received by each BS along the first 30 seconds, both using the Traditional approach (see Figure 3a) and our DSM scheme (see Figure 3b). As shown, BS7 is receiving 5,355 messages (a value

(a)

(b)

Fig. 2: Simulation scenario during the first time period (i.e., from 0 to 30s) when considering *(a)* Traditional and *(b)* DSM approaches. Blue dots represent regular BSs and red triangles represent those that are receiving a great number of messages. Operational SCs are represented by yellow squares.



(a)

(b)

Fig. 3: Number of messages received by each BS during the first period (i.e., from 0 to 30s) when considering *(a)* Traditional and *(b)* DSM approaches.

higher than the UsageThreshold defined). However, using the DSM, it receives 4,487 messages. This represents a 16.21% reduction.

After 60s, BS2 and BS7 present an overload situation. Hence, the CNA activates the SCs that are closer to overladed BSs. Using the Traditional approach BS2 and BS7 receive 5,879 and 5,037 messages, respectively, while using our DSM scheme they receive 4,842 and 3,598 messages. These values represent a reduction of 28.57% and 17.64%.

The results obtained during the third period studied (i.e., from 60 to 90s) are very similar to those obtained during the second period. In particular, using the Traditional approach BS2 and BS7 continue presenting an overload situation, and the CNA activates the same SCs. In this case, the reduction of messages obtained after this activation is 32.18% and 16.67% for BS2 and BS7, respectively.

Finally, Figures 4 and 5 present the results obtained during the last time period. As shown, in that case BS1, BS2, and BS7 are overloaded, and hence, using our DSM approach the Cognitive Network Agent (CNA) activates those SCs closer to them. In this case, the reductions of messages obtained after this activation are 13.12%, 34.02%, and 11.34% for BS1, BS2, and BS7, respectively. Notice that even using DSM, BS7 continues overloaded. This suggests us that more SCs should

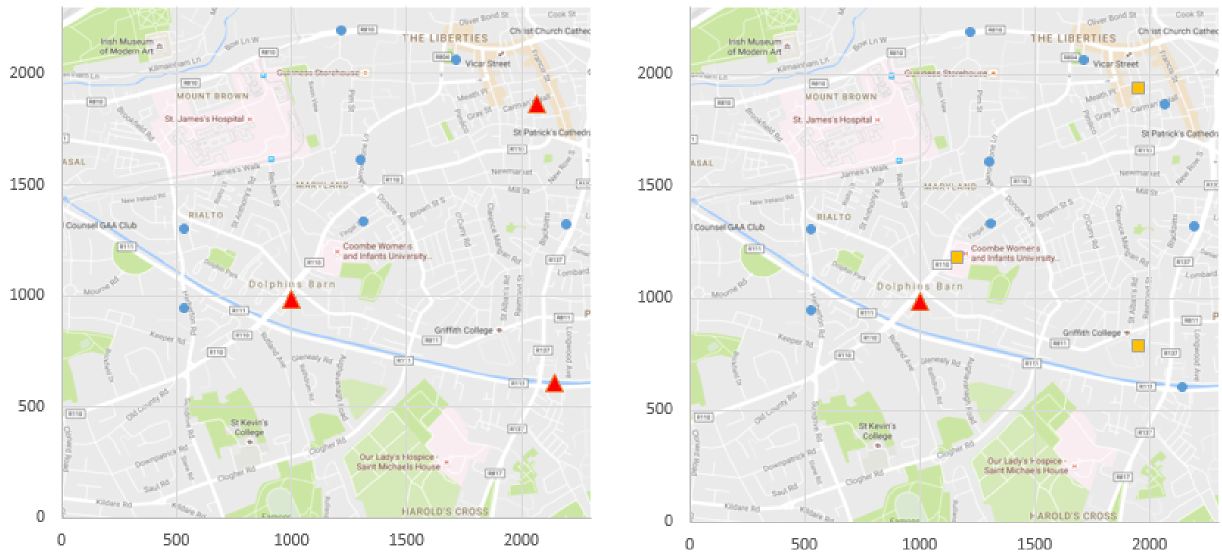


Fig. 4: Simulation scenario during the fourth period (i.e., from 90 to 120s) when considering *(a)* Traditional and *(b)* DSM approaches. Blue dots represent regular BSs and red triangles represent those that are receiving a great number of messages. Operational SCs are represented by yellow squares.

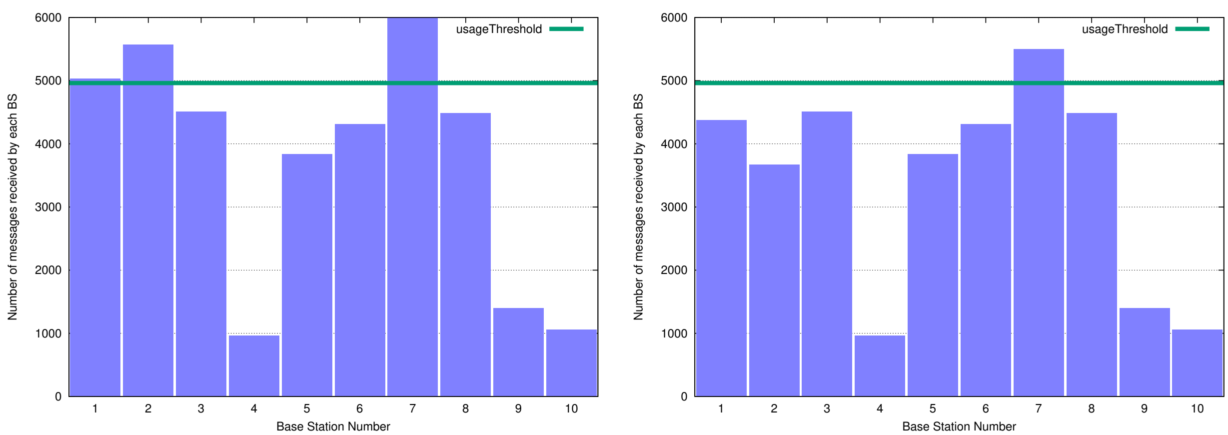


Fig. 5: Number of messages received by each BS during the fourth period (i.e., from 90 to 120s) when considering *(a)* Traditional and *(b)* DSM approaches.

TABLE II: Total number of messages received during the different periods analyzed. The messages received by operational SCs appear in brackets.

	Messages correctly received			
time period	from 0 to 30s	from 30 to 60s	from 60 to 90s	from 90 to 120s
Traditional	30,495	34,014	35,930	37,344
DSM	35,995 (6,368)	41,944 (10,407)	45,088 (11,884)	53,681 (19,593)

TABLE III: Percentages of communication improvement and traffic offloaded during the different periods analyzed when using our DSM approach.

time period	from 0 to 30s	from 30 to 60s	from 60 to 90s	from 90 to 120s
Comm. Improvement	18.04%	23.31%	25.49%	43.75%
Traffic offloaded	2.84%	7.28%	7.59%	8.72%

be activated in some specific situations since higher densities cannot be correctly managed by activating only a single SC.

While assessing our proposal, we not only focus on reducing the BS overloads, but also focus into increasing the communication capabilities of the overall system, in terms of the number of messages sent by vehicles that are successfully received by any infrastructure element. In particular, Table II presents the comparison of our DSM scheme and the Traditional approach in terms of number of messages correctly received. We have divided the values obtained along the four time periods studied, also we have included the number of messages received by the activated SCs. Table III presents both the percentage of communication improvement (in terms of messages correctly received) and the percentage of traffic offloaded (in terms of messages managed by the BSs) during the different periods analyzed. As shown, our DSM scheme is able to increase the number of messages correctly received by the infrastructure (up to a 43.75%), in particular when more SCs are active, while also reducing the traffic managed by overloaded BSs (up to a 8.72%).

VI. Conclusions

In this paper we introduced the Dynamic Small cell Management (DSM) architecture, which is dynamically composed by 3G BSs and 802.11p SCs. DSM shifts the 802.11p-based V2I vehicular networking paradigm toward a paradigm based on HetNets, completely focused on increasing communication capabilities while mitigating data traffic congestion.

We studied the feasibility of our approach based on real network deployment from a mobile operator in Dublin city, Ireland. In particular, we simulate vehicles, which are running data-intensive applications, communicating with a Traffic Control Center (TCC). This data will be delivered by means of the BSs available in the scenario. However, when some of these BSs are overloaded, the Cognitive Network Agent (CNA) would activate one (or more) SCs to reduce network congestion as well as to increase the overall network performance in terms of messages correctly received by the infrastructure.

Our study demonstrated the viability of our DSM approach, providing dynamic on-demand networks, that fulfill the current and forecasted vehicular nets demand with more efficiency than current operators' approaches.

As future work we plan to study different SC activation strategies, applying multi-criteria and/or multi-objective decision making techniques, as well as to extend our mechanism to include heterogeneous ownership scenarios, i.e., those considering infrastructure owned by different companies. Furthermore, we will study the performance of DSM at different layers considering metrics such as handover latency, network latency, and QoS.

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