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Extending the iTETRIS platform for Smartphone Sensing and Communication Simulation

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Abstract

Smartphones are nowadays powerful sensing platforms equipped with multiple communication interfaces. Considering in particular the WiFi-Direct technology in a transportation context, smartphones are capable of sensing various types of traffic conditions and self-organize in proximity networks to consolidate the sensed data and transmit it to the transport infrastructure. The high penetration rate of smartphones in road users, the scale of road networks and logistic reasons make simulation studies a preferred choice for proximity-based traffic sensing applications. In this paper, we present the extensions to the iTETRIS ITS simulation platform required to support proximity services based on the WiFi-Direct technology in a mobile vehicular environment. We describe the added WiFi-Direct features in ns-3 as well as in the Application module, and through early simulations, we shed lights on some limitations of WiFi-Direct procedures to efficient proximity networking for traffic sensing.

Keywords: sensors ; smart ; phone ; proximity; service ; WiFi ; direct ; communication ; iTETRIS ; architecture ; simulation ; ITS

Résumé

Les smartphones sont de nos jours de puissantes plateformes de capteurs équipées de multiples interfaces de communication. En considérant la technologie WiFi-Direct dans un contexte de transport, les smartphones sont capables de capter plusieurs types de conditions de trafic et de s'auto-organiser en réseaux de proximité afin de consolider leurs données avant de les transmettre à l'infrastructure de transport. La forte pénétration des smartphones chez les usagers de la route, des raisons d'échelle et de logistique font des analyses par simulation une approche particulièrement adaptée pour le développement de services de proximité pour l'évaluation du trafic routier. Dans ce papier, nous présentons les extensions ajoutées à la plateforme de simulation iTETRIS afin de supporter les services de proximité basés sur la technologie WiFi-Direct dans un environnement véhiculaire. Nous décrivons les nouveaux composants de WiFi-Direct inclus dans ns-3 et dans le module d'application, et par simulation, nous identifions quelques limitations des procédures du WiFi-Direct pour la création de réseaux de proximité à des fins de d'évaluation de conditions de trafic.
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Mots-clé: capteurs, smart; phone; proximité ; service ; WiFi ; direct ; communication ; iTETRIS, architecture ; simulation ; ITS

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1. Introduction

With their various sensing capabilities and multiple communication interfaces, modern smartphones have gone far from the good-old telephone-enhanced organizer. Smartphones are already currently carried by a wide range of actors (vehicles, pedestrians, motorcycles, …) and that makes them a very promising mobile sensing and communication platform for crowd-sensing, proximity and social services. In particular, with the recent WiFi-Direct technology, smartphones may interact with other smartphones to form an organized dynamic and spontaneous mobile sensing network.

The EU FP7 ICT COLOMBO (2012-2015) [COLOMBO] project for intelligent traffic management uses such network in the particular context of smart traffic lights, by using smartphones to provide traffic surveillance information required by COLOMBO's traffic light control algorithms. A strong focus is put on the design of solutions that explicitly conserve the environment, by delivering guidelines for constructing environment-friendly traffic light controls as well as stimulating emission-optimal driver behaviors. The V2X technology is usually the preferred option to perform traffic surveillance tasks, but it is also not expected to have the sufficient penetration rate in the next decade. One key innovation is therefore to exploit the additional information sensing and communication capabilities of WiFi-Direct enabled smartphones carried on board of participating non-V2X-equipped vehicles to compensate for the early low penetration rate of V2X-equipped vehicles. One major challenge is to efficiently consolidate traffic state information obtained from a low fraction of high quality traffic data provided by V2X-equipped vehicles with a larger fraction of lower quality data obtained from the smartphone sensing capabilities on board of non-V2X-equipped vehicles.

The COLOMBO project mainly works on employing and extending open-source solutions around the iTETRIS traffic management platform [iTETRIS] to support state-of-the-art optimization methods and techniques exploited to effectively and efficiently design the investigated protocols. The iTETRIS platform is an open-source ITS simulation platform for large-scale deployment environments, developed by the FP7 ICT iTETRIS project to evaluate the feasibility and performance of ITS traffic management applications based on V2X communications. Within the iTETRIS project, ns-3 has been extended to support V2X technologies and to be compliant with the ETSI ITS standards to support V2X-related communications.
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Within COLOMBO, the iTETRIS architecture is further extended to support the simulation of deployment environments where smartphone-based sensors, communications, and applications are exploited. The extended iTETRIS architecture presents several original characteristics. First, key communication functions of the new WiFi-Direct standard have been integrated into ns-3: WiFi-Direct is the lead ad-hoc communication protocol available in major recent smartphones (and even other wireless-enabled smart objects), and is also the major emerging competitor for sensor-related communication technologies, such as Bluetooth and Zigbee. Second, the application module is rethought to support smartphone-related applications (e.g., stemming from the interaction of smartphone apps with in-vehicle sensors, communication capabilities, devices, …), jointly with other ITS-related ones. Finally, the ambitious goal is to obtain a simulation environment that integrates smartphone-related communication technologies and applications in the larger context of transport applications in smart cities.

The rest of this paper is organized as follows. Section 2 describes the WiFi-Direct standard and assesses some required extensions for vehicular communications. Section 3 introduces the iTETRIS platform and provides details on the communication and application structure. Then, Section 4 sheds light on the developed extensions to the iTETRIS platform required by the COLOMBO project for WiFi-Direct related traffic surveillance services. Finally, Section 5 brings our work in perspective to the larger roadmap related to the evaluation of the feasibility of WiFi-Direct for vehicular environment.

2. WiFi-Direct support for Smartphone P2P Communications

WiFi-Direct is a specification of the WiFi-Alliance [WiFi Alliance] to fill up the gap in the IEEE 802.11-2012 standard in the IBSS mode. WiFi-Direct is a promising access technology for Proximity Services and Social Networking due to the full support of dedicated communication between smartphones. WiFi-Direct is available in most modern smartphones (Android, Windows phones,..) and is expected to be a major player in transportation in order to spontaneously exchange data gathered by the smartphones' increasing sensing capabilities.

Although based on the WiFi standard, WiFi-Direct provides additional functionalities required for peer-to-peer (P2P) discovery, service discovery and group management. WiFi in IBSS mode does not clearly describe how the scanning process and the IBSS formation should be conducted to find a common frequency between all nodes in an IBSS network, and does not leave enough flexibility to select an appropriate IBSS leader. In WiFi-Direct, the objective of the P2P Discovery is to quickly find P2P devices and determine the P2P device to which a connection will be attempted, or the set of P2P devices that will form a P2P Group (IBSS).

The *P2P Discovery* is composed of three major phases: *Scan, Listen and Search*. The *Scan phase* is similar to the scan procedure of IEEE 802.11-2012. If a P2P device is found during that phase, the subsequent phases are not required. If not, P2P devices will first start a *Listen phase*. During that phase, a P2P device does not transmit and remains tuned to a given channel for a random time to wait for *Probe Request* messages of other P2P devices. If a Probe Request message is received, a P2P device sends a *Probe Reply* message back, and a negotiation and group management procedure is started. If not, then the P2P device moves to the *Search phase*. During that phase, the P2P device is active, moves to a given channel for a random time, sends *Probe Request* messages and waits for *Probe Reply* messages. If none are received after a given time, the P2P device moves to the next channel and repeats the procedure until it moves back to the *Listen phase*. The objective of this procedure is to increase the chances of P2P devices to converge to a P2P rendezvous channel and start the P2P negotiation. The P2P Discovery procedure is illustrated with more details in Figure 1.

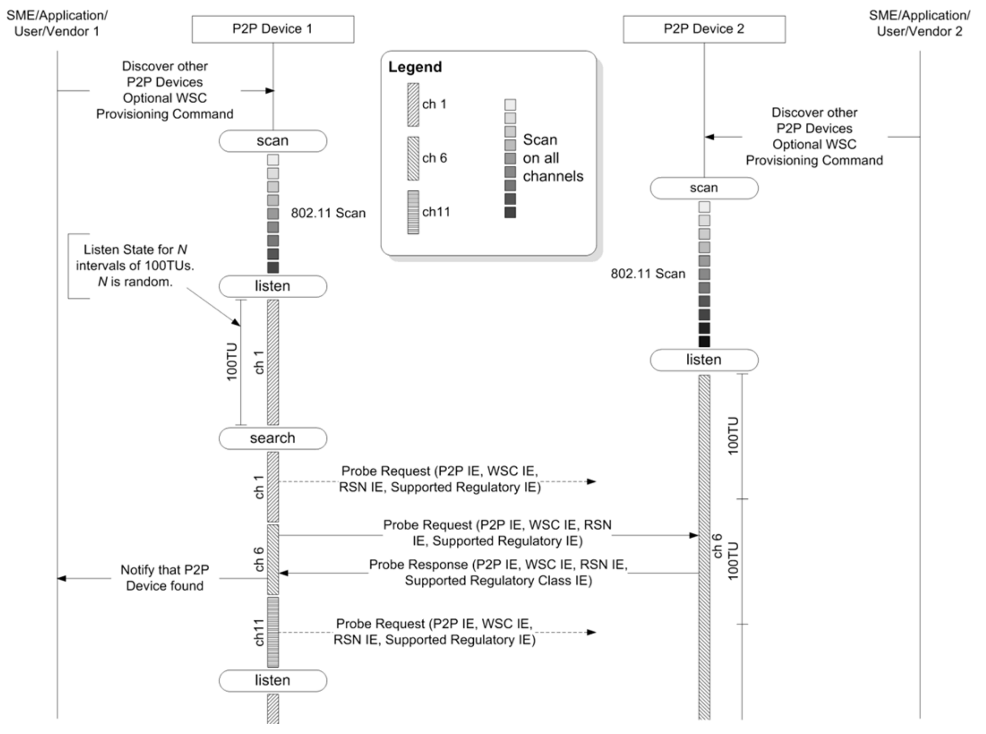


Figure 1 WiFi-Direct Peer Discovery [source: WiFi Alliance]

P2P Service discovery is performed jointly with *P2P Discovery* upon successful exchange of a Probe Request/Probe Response between two P2P devices. In the context of the COLOMBO project, services may be seen from two aspects. The key service is called “awareness”, which is the capabilities to transmit its own GPS position and speed. Other types of services may also be found, which could be for instance consolidated traffic flow data or other types of sensed data. Considering that various smartphones might have various quality for their ‘awareness’, the concept of ‘service’ is critical, as it leaves a P2P device the ability to join groups of similar service qualities and help the consolidation of traffic flow data between P2P devices.
Once a service is discovered, the next step is to create or join a P2P Group and elect or rally a *P2P Group Owner (GO)*. This procedure is based on a negotiation between P2P devices over several *P2P GO messages* exchanged

between P2P devices. The P2P device elected as Group Owner takes the control of the P2P group. A node may simultaneously be group owner of one group and member of another one. In the context of the COLOMBO project, groups are expected to be formed based on fusion/consolidation of 'awareness' or traffic flows being monitored by each P2P device.

WiFi-Direct has further functionalities, in particular related to authentication or service management but are not expected to play a critical role in the context of COLOMBO.

3. The iTETRIS Simulation System

iTETRIS is a multi-simulator platform federating a traffic simulator SUMO [SUMO], a network simulator ns-3 [ns3] and an application module around an interface called the iTETRIS Control System (iCS) (see Figure 2). A detailed description of iTETRIS may be found in [Rondinone et al.]. Smartphone support in iTETRIS has impact mostly on the network simulator ns-3 and on the application module and its interaction with ns-3.

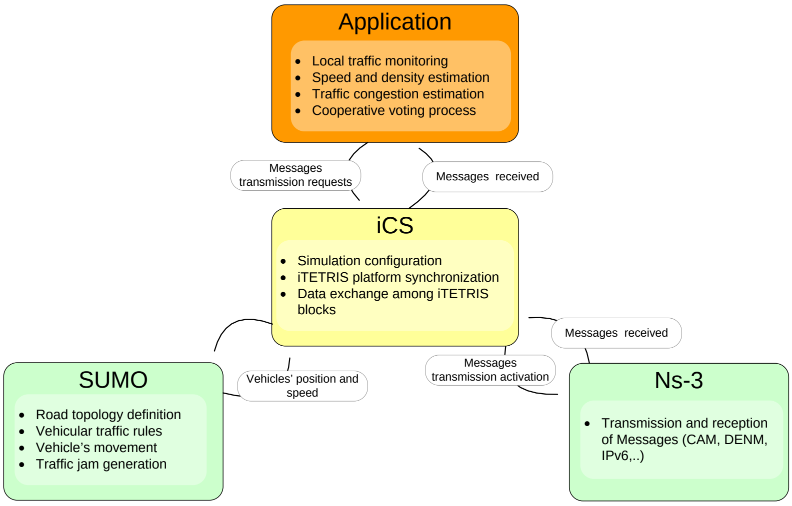


Figure 2 The iTETRIS simulation system, where iCS stands for iTETRIS Control System.

Ns-3 does not support natively V2X communications, and has been extended by the iTETRIS project to integrate an ETSI-compliant V2X stack parallel to the IPv6 stack. The C2C stack supports geographic addressing and include various geographic routing protocols (geobroadcast, geounicast) along with unicast and broadcast support. A communication technology selector allows an iTETRIS application to select the access technology and the communication stack to transmit data. As it may be illustrated on Figure 3, a new access technology, *Dedicated Short Range Communication* (DSRC, aka IEEE 802.11p) is supported along with other infrastructure-based technologies such as UMTS, DVB-H or WiFi. It may be noted that although both infrastructure and ad-hoc WiFi are supported by ns-3, the iTETRIS extensions only include support for infrastructure WiFi, as the ad-hoc communication required by V2X technologies is handled by DSRC. The full support of ad-hoc WiFi as well as the WiFi-Direct primitives are one major extension to the iTETRIS that is required for smartphone sensing and communications.

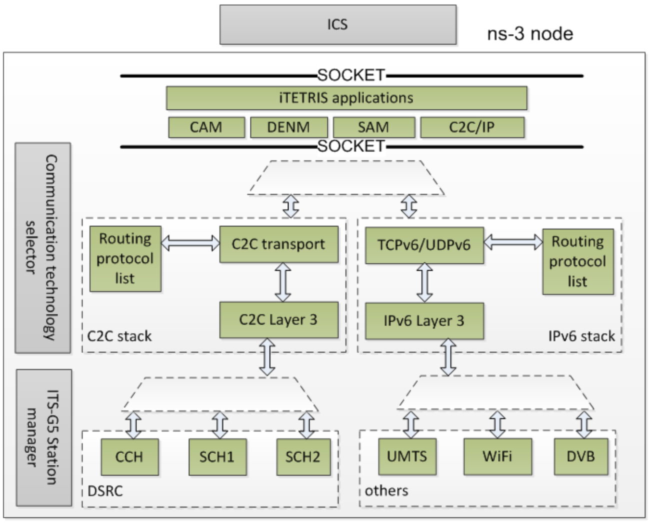


Figure 3 ns-3 V2X stack architecture and components, where C2C stands for Car-2-Car, and CCH, SCH, stands for Control CHannel and Service CHannel, respectively.

The iTERIS platform includes an Application module, which may control and interact with ns-3 and SUMO through 'subscriptions'. As illustrated on Figure 4, an application (a node) may subscribe to an ns-3 request for a Unicast transmission, or subscribe to an SUMO request for GPS positions. Subscriptions are an extensible method to partially control ns-3 or SUMO from the Application module. Data fusion and consolidation required for the Traffic surveillance applications in COLOMBO are implemented in the application module. In the iTETRIS design, the Application module deals only with application-level data (packet, positions), but in the context of the COLOMBO project, cross-layer methods are required. For instance, A P2P neighbor table, a signal quality (RSSI) or the power a packet has been transmitted with would typically be required in order to efficiently form a WiFi-Direct P2P Group to fusion traffic data. Accordingly, the subscription mechanisms should be extended for cross-layer support, and the P2P neighbor table as well as P2P Group management primitives should be placed at the application level instead at a lower protocol layer.

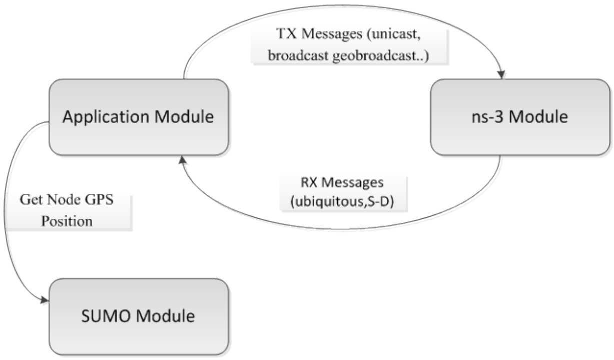


Figure 4 Application module interaction with ns-3 and SUMO through subscriptions

4. iTETRIS Extentions for Smartphone and WiFi-Direct

4.1. Extension to ns-3

The full support of WiFi-Direct in iTETRIS is not required for the purpose of the COLOMBO project. We abstracted the support of WiFi-Direct with three new extensions in ns-3. First, we added the support of the ETSI ITS G5C band at 5.5GHz – 5.7GHz. In the COLOMBO scenarios, WiFi-Direct is assumed to operate in such frequency band (see Figure 5) first for proximity reasons with the C2X ETSI ITS G5A and ITS-G5B bands, and also for flexibility reasons between ITS services, which could be interchangeably exchanged on C2X on ITS G5B or WiFi-Direct on ITS G5C transparently to the traffic surveillance application.

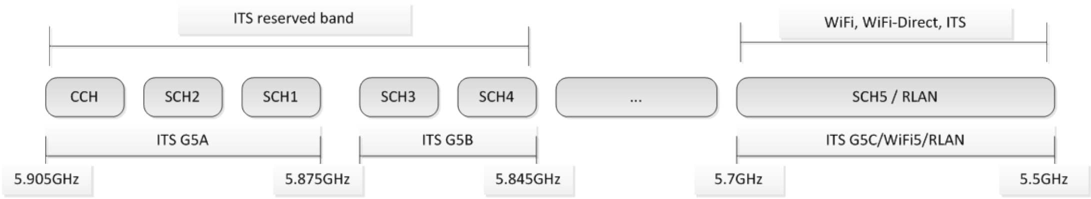


Figure 5 Spectrum Allocation at 5GHz - ITS G5, WiFi 5, and WiFi-Direct

As illustrated in Section 2, WiFi-Direct operates in the IEEE 802.11 ad-hoc mode, which ns-3 already supports. However, the *P2P Discovery* procedure is based on a cognitive principle, where the IEEE 802.11 scanning phase is enhanced with a *listen-search* phase to converge to a rendezvous channel between P2P devices. In ns-3, the scanning functions are part of the *ns-3::station_manager*, which role is to detect *beacons/probe-requests* and manage the IBSS. A new *ns-3::wifi-direct-station_manager*, based on the *ns-3::vehicle-station_manager*, has been added to the ns-3 stack, with a *ns3::wifi-direct-scan_manager* handling the enhanced functionalities required for WiFi P2P discovery.

Table 1 WiFi-Direct Peer and Service Discovery

Peer2Peer Discovery Frequency	Avg Delay Peer Discovery	Avg Delay Service
Synchronized	884.81 [µs]	0.8234 [s]
Non synchronized	2.5146 [s]	3.56 [s]

Table 1 illustrates initial results of the implementation of the *P2P Discovery* procedure on ns-3 iTETRIS. We show the time required to discover the P2P device (Avg. Delay Peer Discovery) as well as the required time before communication may be established (Avg. Delay Service). Depending if the two P2P devices are starting their *P2P Discovery* procedure from the same channel (synchronized case) or from different channels (non-synchronized case), we obtained drastically different delays. Considering data fusion algorithms for traffic surveillance, requiring more than 2 [s] to discover a P2P device in a mobile environment is too high. The transmitted data might indeed be deprecated and the P2P group might break even before it is created. One conclusion we can draw from this is that we need to synchronize the P2P devices so that the listen/search phases may converge faster. A potential solution would be to agree on a known channel for P2P Discovery. This channel should be reserved for P2P Discovery, as otherwise heavy traffic would lower the efficiency of discovery procedure. Accordingly, this would mean that upon convergence of the P2P Discovery, both peers would also agree on a dedicated alternate channel for their data transmission and group formation. This approach is conceptually similar to the ITS G5 technology, where services are announced on a well-known service channel (SCH1), before switching to a dedicated data service channel.

The *P2P Group Management* is not integrated in ns-3 directly but rather at the application module in order to leave more control to the COLOMBO applications to dynamically join/leave groups based on traffic surveillance requirements. The last extension consists of a *ns3::iTETRIS_Service Provider* (SP) and *ns3::iTETRIS_Service Consumer (SC)* applications. Both SP and SC applications are is not tightly connected to a particular access technology (WiFi-Direct, DSRC) or protocol stack (IPv6, C2X), but we linked to WiFi-Direct C2X Stack by default (see Figure 6).

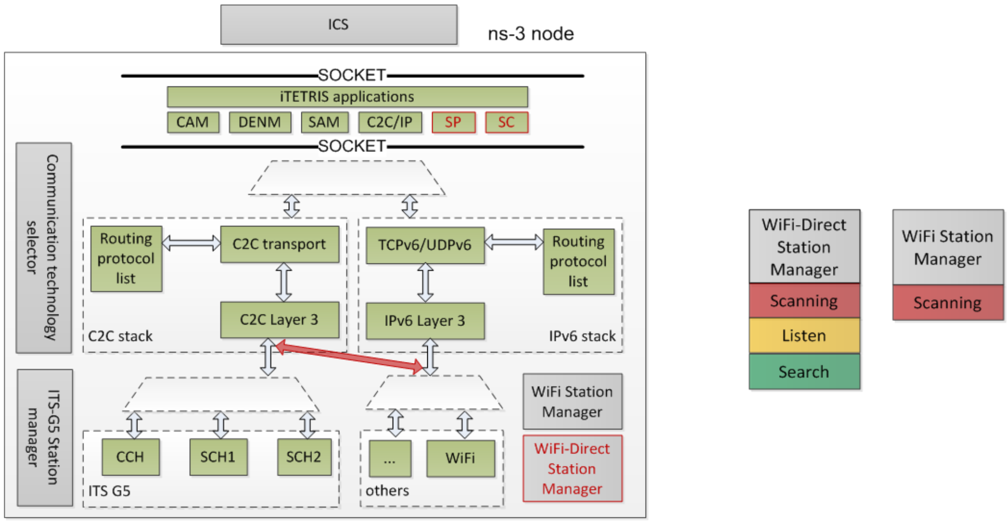
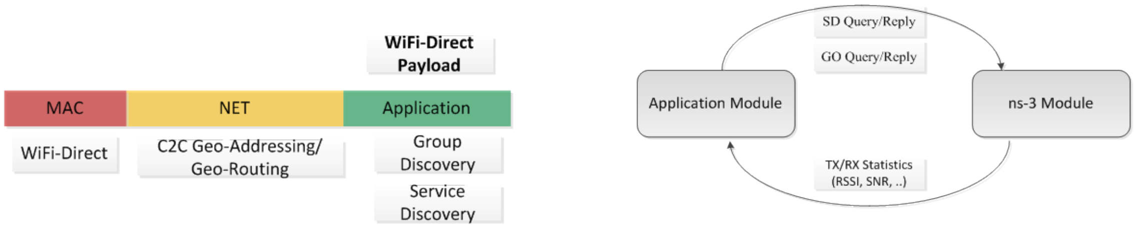


Figure 6 ns-3 extensions for COLOMBO (in red) - WiFi-Direct support, Service Provider (SP), Service Consumer (SC) as well as C2C Stack on WiFi-Direct. The WiFi-Direct Station Manager implements two new WiFi-Direct P2P Discovery (Listen/Search phases)

4.2. Extended Application Support

We separated the various WiFi-Direct functionalities in two blocks: we let the *P2P Discovery* be autonomously handled by ns-3, while all other functionalities are implemented in the Application module. The reason for this design choice is to allow more flexibility to tweak WiFi-Direct without needing to know ns-3. Accordingly, the following WiFi-Direct network services are implemented in the Application module: *P2P Service Management (SM)*, *P2P device Neighbor Table (NT)*, and *P2P Group Management (GM)*. In WiFi-Direct, *P2P SM* lets a P2P device offer a service or select other P2P devices offering a service it is interested in (e.g. printing, file exchange, Internet access). In COLOMBO, the *P2P SM* is extended to support the discovery of the type and quality of data provided by the P2P device, as it will ease the selection of peers for data fusion. Such information is obtained by the exchange of Application-level *Service Discovery Query/Reply* messages (*SD Query/Reply*), letting full freedom to the application designer of the content and type of data transmitted in the SD Query/Reply messages.
Most data fusion algorithms are based on clustering principles, which require a vision of the larger P2P topology. A *P2P Neighbor Table* is therefore required also at the application level to estimate which of all P2P devices available could form a stable P2P Group for efficient traffic data consolidation. Finally, COLOMBO also extends the *P2P Group Management* process with the capabilities to elect a *Group Owner (GO)* based on group stability metrics rather than either randomly or based on service interests only.

Figure 7 depicts the interaction between the Application and ns-3 modules, where an application could send/receive Application-level message (eg. *SD or GO Queries/Replies*), as well as configurable communication statistics (e.g. RSSI, SNR, TX power etc..) required to build a stable P2P Group. Figure 7 also illustrates the content and structure of such typical Application-level message where messages related to WiFi-Direct P2P devices are in the MAC part, the geo-addressing (GPS position) are in the NET part, and data related to P2P Service or Group Discovery are in an proximity-service application part. This structure obviously neither respects the OSI layer nor the WiFi-Direct standard. Yet, it helps iTETRIS application designers to have control on these key phases and are not expected to impact the coherence of the traffic surveillance applications developed in COLOMBO.



a) Message Structure b) Interaction between the Application and the ns-3 module

Figure 7 Application-level extension to support WiFi-Direct Service Management & Group Management.

5. Summary & Outlook

The COLOMBO project aims at using WiFi-Direct-equipped smartphones for efficient distributed traffic surveillance. WiFi-direct having been developed for quasi-static environments, one of COLOMBO objectives is to evaluate the capabilities of WiFi Direct to dynamically inter-network smartphones in highly mobile conditions. Simulation studies are the natural choice to this objective and are conducted in COLOMBO on the iTETRIS ITS simulation platform. We described in this paper the WiFi-Direct standard and the extensions we developed on the iTETRIS platform to support it. Initial simulation results showed that WiFi-Direct is particularly sensitive to highly mobile environments and low quality communications. Accordingly, we proposed the following modifications to WiFi-Direct to adapt it better to a vehicular environment: the assignment of a 'well-known' service announcement channel to shorten the peer discovery process, and an enhanced group formation based on topology and communication quality to form groups that would be stable enough for traffic-related data fusion.
Our next step is to integrate this modified WiFi-Direct with advanced data fusion algorithms in more general traffic scenarios in order to evaluate how the WiFi-Direct protocols and the traffic surveillance applications are inter-related.

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