Ad hoc Network QoS Architecture For Cooperative Unmanned Aerial Vehicles (UAVs)

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***Abstract*—New trends in cooperative human-machine system use in the domain of transportations are rising. These systems rely on a powerful interaction, or collaboration between humans and machines. This collaboration is made possible by an exchange of information between actors (humans or machines, commonly referred to as agents) in the transport of good or people. Cooperation in such a dynamic environment implies that the actors may have varying roles and/or tasks assigned to them, thus leading to changes in their communication needs. This paper presents an ad hoc network QoS architecture oriented toward cooperation between agents, called DAN. This architecture is aware of agents needs in term of communication and is able to provide, or inform of the impossibility to provide, a quality of service in accordance to those needs.**

***Index Terms*—QoS, Communication Architecture, MANET, Cooperative systems.**

I. Introduction

In the transportation domain, there are two types of actors: humans and machines (that we will both refer to as agents). A look back into the history of their relationship reveals that human has always been the operator. He has been in charge of the vehicle control and the traffic control.

Thanks to the technological innovations, it is possible to integrate advanced automated assistance systems to these tasks which leads to a complex and efficient interplay of humans and automation.

The European research project, D3CoS (Designing Dynamic Distributed COoperative human-machine Systems) [1], funded by the ARTEMIS-JU, offers solutions for the human-machine cooperation by developing affordable Methods, Techniques and Tools (*MTT*), oriented toward the specification, development and evaluation of cooperative systems. D3CoS is dedicated to the transportation domain, and deals with four application sub-domains: manned aircraft, automotive, maritime and Unmanned Aerial Vehicles (UAVs).

In such dynamic systems, called a DCoS (*Dynamic COoperative System*), a set of mobile agents are collaborating between themselves by exchanging information, in order to accomplish several tasks.

Cooperation in dynamic environment implies that the agent may be assigned different roles and different tasks as time passes. The different roles imply that the agent needs in terms of communication may differ from agent to agent. Moreover, changes in tasks and roles may lead to variations in terms of the communication needs of each individual agent.

Mobile Ad hoc NETworks (MANET) are the suitable system to be used to have the mobile agents communicate as they offer a self-configuring network with wireless links. However, supporting QoS in MANETs is a challenging issue. The mobility of nodes in such a network forms an arbitrary time-varying network topology which may affect QoS factors such as the end-to-end delay or loss rate.

This paper presents DAN (DCoS Ad hoc Network) which is an ad hoc network QoS architecture designed for dynamic cooperative systems, aware of the agent QoS needs and able to provide, or inform of the impossibility to provide, a QoS level in accordance with those needs. It allows each agent to advertise its requirements in term of QoS , and provides service differentiation to meet those requirements.

DAN is designed for the D3CoS project and though it could be used for any of the sub-domains (manned aircraft, automotive, maritime and UAVs), it is being developed for micro UAVs running the Paparazzi system [2].

This paper is structured as follows. Section II discusses related works. Section III presents the DAN architecture followed by the evaluation and the simulation of this architecture in section IV. Section V presents some concluding remarks.

II. Related Work

If solutions as IntServ [3] and DiffServ [4] exist for wired networks, in wireless networks, more work has been done toward enhancing the global performance provided by the network rather than offering service differentiation according to applications or user requirements. Two notable propositions have been made though: INSIGNIA [5] and SWAN [6].

INSIGNIA, the "In-band Signalling Support for QoS In Mobile Ad hoc Networks" is the first signalling framework designed for MANETs to support QoS, it is based on *In-Band Signalling*. This approach uses the header of IP packets containing data to signal resource reservation. INSIGNIA, with admission control collaboration, reserves network resources to support QoS for real-time traffic. It allows Real-Time Packets to specify their bandwidth needs by adding a new IP option in each IP header to establish, restore and adapt resources between source-destination pairs.

INSIGNIA necessitates a modification of the IP header which we want to avoid in order to simplify implementation and tests of our proposal.

Another model proposed for MANETs is SWAN, the "Stateless Wireless Ad hoc Network", which is a distributed network QoS with stateless approach designed to provide end-to-end QoS in ad hoc networks. It differentiates two traffic classes: real-time and best-effort. SWAN uses rate control for Best-Effort traffic and sender based admission control for real-time traffic. The admission control decision in SWAN, is taken at the source node after probing the bandwidth availability in the network between the source and the destination.

Other solutions than SWAN and INSIGNIA exist that also include the MAC layer in the mechanisms used to provide the required QoS. If it is clear that taking into account interferences and channel occupation increases performances, this requires specific hardware that is not available off-the-shelf. As our goal is to actually implement the retained solution on low cost, lightweight devices, we decided not to go in that direction.

In the same manner, if our solution closely resemble INSIGNIA, we chose not to use in-band signalling in order to avoid Operating System (OS) level programming if possible. As a consequence, DAN architecture, presented in the next section can be developed entirely as user-space software.

III. DAN Architecture

The DAN architecture is a combination of a number of mechanisms that support QoS. In DAN, applications may require their needs in term of QoS for each traffic flow. Therefore, DAN mechanisms differentiate services and assure the necessary resources using a simple methodology.

DAN supports a traffic differentiation into three classes adapted to UAV mission scenarios: urgent, premium, and best-effort. The urgent class is used for sporadic messages with the highest priority (e.g.: `battery low` message from a UAV), it will benefit from the lowest delay and the highest reliability. The premium class is designed to offer a low jitter, low delay, high reliability service. It will primarily be used for audio/video flows.

As shown in figure 1, DAN is composed by a specific API (Application Programming Interface) to connect the application to the other DAN modules which are:

- *DAN agent module* which is the contact of the application and the manager of the other modules. It maintains the list of reserved premium flows.
- *Admission controller (AC) module* that is responsible for calculating the locally available resources and the decision making about flow reservations.
- *Classifier module* that uses queueing and scheduling strategies to send each packet according to its class requirements.

DAN allows the application to advertise their needs in terms of QoS, using a specific API in order to communicate with the DAN agent. Including the classical UDP and TCP Sockets, other sockets are used to exchange messages containing flow information.

In order to differentiate traffic classes, a classifier mechanism is used. It classifies and marks each packet with its class, after that those packets are treated according to their traffic requirements. Basically, there are three traffic classes:

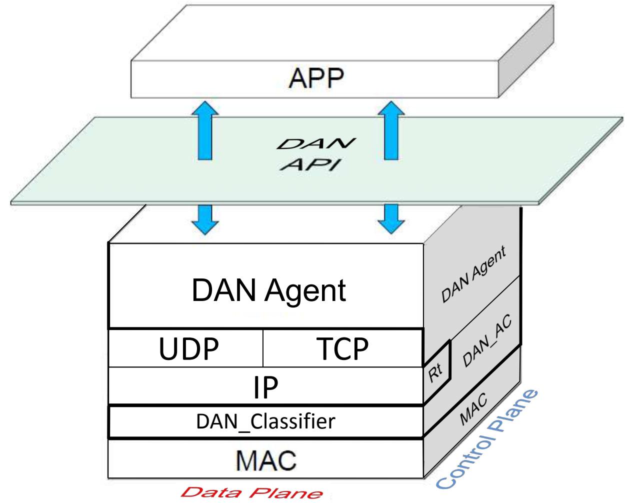

Fig. 1. DAN Architecture

- *Urgent traffic* is used for sporadic messages that have the highest priority and required low latency. In cooperative UAVs operations, it may be an information about urgent result, or critical situation as the aircraft energy level.
- *Premium traffic* is used for data flows that require QoS needs in terms of low loss rate and low latency such as real-time video.
- *Best-effort traffic* is used for data flows with no QoS requirements such as GPS, periodic geographical information.

For the Premium class, data flows which have some QoS requirements, a soft state mechanism is applied to guarantee the QoS needed using a hop-by-hop signalling, to reserve the necessary resources, and a control rate to inform the admission controller about the local resource availability and to limit the rate of high priority classes.

DAN exchanges three types of signalling to guarantee the required resources:

- Reservation message: used to inform intermediate nodes about the new flow requirements in order to reserve the necessary resources.
- Error message: sent to the source of the flow in case the intermediate node cannot provide the resources needed or in case an intermediate node receives premium flow without previous reservation.
- Close message: used to close a reservation.

Moreover, data packets are used to refresh flow reservations using IP header information.

When a premium traffic is being sent, the application must inform DAN agent first; this will send *reservation messages* containing the required bandwidth for the traffic. Each intermediate node receiving this message processes it with the admission controller module.

The admission controller has a specific capacity in term of bandwidth reserved for the premium traffic. This capacity is calculated using measures that take into account the total link capacity in term of bandwidth and the interference.

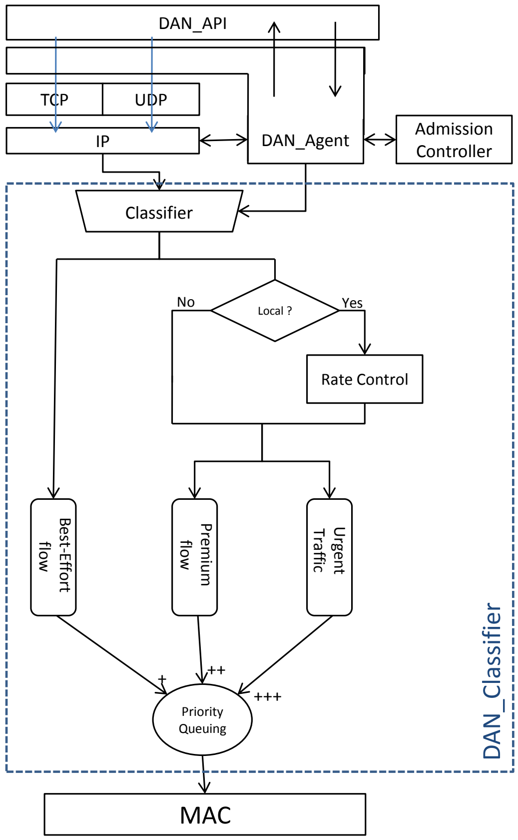

Fig. 2. DAN Mechanisms

Depending on its local capacity, the admission controller may accept or deny the reservation.

In case where the node has enough resources, it updates its flow list and decreases its capacity taking into account the needs of the new reserved flow and it forwards the reservation message to the next intermediate node. In the case where the intermediate node cannot afford the required resources, it sends an error message to the source containing the amount of the local available bandwidth, which offers the possibility to the application to renegotiate and to reserve the available resources if possible.

After sending the reservation message, the DAN agent waits for an error message during a *Wait To Send* (WTS) time. Then it informs the application to start sending data packets, supposing that the reservation was accepted by all the intermediate nodes in the selected route.

In MANETs, routes may be removed and other may be created. Therefore, routes reserved for data may also change, in this case, the new intermediate node, receiving the premium packet data, treats it as a best-effort traffic, since there is no reservation for this flow and sends an *Error message* to the source in order to inform it to re-establish a reservation for that flow. A reservation is maintained for a period of time called *Wait To Clear* (WTC), refreshed with the reception of data packets of each flow. After the WTC, the reservation is cancelled.

This section presented DAN architecture, which provides service differentiation into three classes (urgent, premium and best-effort) using queueing, scheduling and signalling strategies. It allows to control premium and urgent traffic rate in each sender and to satisfy their requirements by reserving network resources for premium class in a soft-state way which reduces the traffic loss rate and delay.

IV. Evaluation of DAN

The following section describes the evaluation of the wireless flow system using DAN. The aim of the simulation is to evaluate DAN effects on the delivery of each traffic class in a mobile UAVs multi-hop network using the network simulator OMNET++ [7]. In such an environment, there is two main constraints, first the signal interference and packet collisions caused by the contention on the wireless channel and second the nodes mobility which causes the routing failure.

In this scenario, 10 mobile nodes are moving freely in an area of 1000m*1000m, using the Random WayPoint mobility model [8].

Each node sends three flows, one urgent, one premium and one best-effort.

Table I presents the simulation parameters.

UAV number	10
routing protocol	AODV
MAC protocol	802.11
Transmission range	250m
Channel capacity	54 Mbps
Premium Capacity in Admission Control	11 Mbps (about 20% of the channel capacity)
Mobility model	Random WayPoint
Urgent traffic /node	500 Bytes sent randomly every [1s,3s]
Premium traffic /node	760Kbps : 950 Bytes every 10ms
Best effort traffic /node	4Mbps: 500Bytes every 1ms

TABLE I
SCENARIO

During this simulation, the number of senders is varying, referring to the network load.

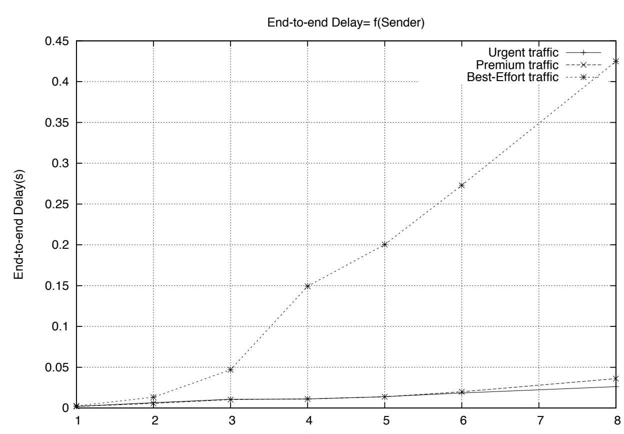

Fig. 3. Average End-to-end Delay vs. number of Senders

Figure 3 shows average end-to-end delay for each traffic class: urgent, premium and best-effort. In unloaded network, the delay is almost the same for the three classes. However, in loaded network (more than 4 senders), there is great difference between the best-effort, delay of which reaches 0.4s, and the other classes. The delays of urgent and premium classes increase very slowly as the number of senders increases.

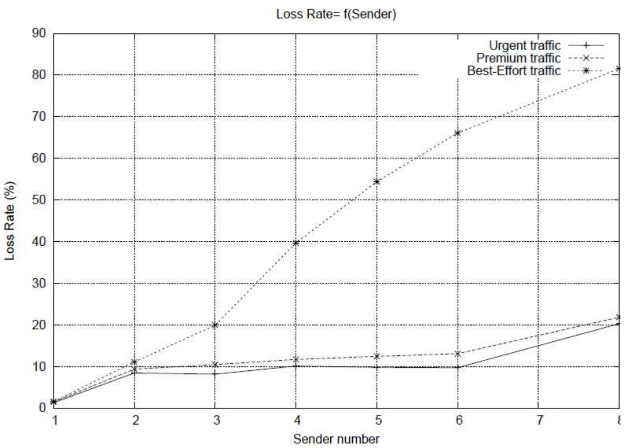

Fig. 4. Average Loss Rate vs. number of Senders

Figure 4 represents average loss rate of each traffic class. It shows a significant difference between Best-effort and the other traffic classes. The loss rates of urgent and premium classes increase slowly (about 10% to 12%) for urgent and premium traffics. This loss is due to interference and packet collisions and node mobility which causes routing failures.

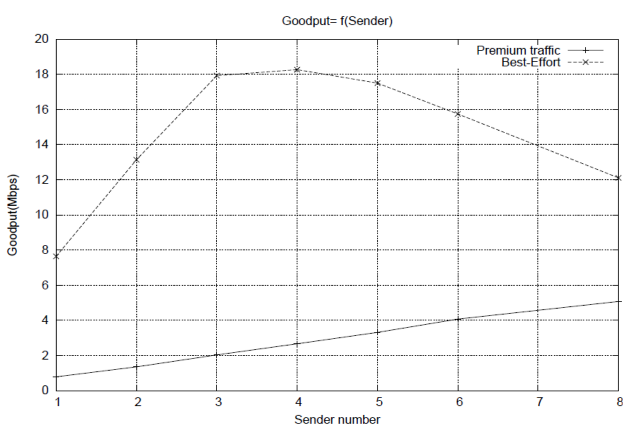

Fig. 5. Average Goodput vs. number of Senders

Figure 5 shows the average goodput of premium and best-effort data flows. It shows that premium goodput increases depending on the number of senders. For instance, for 3 senders, the total theoretical premium traffic is 2.28 Mbps (0.76 Mbps for each node). DAN provides about 2Mbps.

Those results show that DAN provides traffic differentiation and the QoS required for each class in terms of end-to-end delay and loss rate. It affords for urgent and premium traffics low and stable delays and low loss rate under various multi-hop, traffic and mobility conditions.

V. Conclusion

This paper presented DAN, (*DCoS Ad hoc Network*), which is an ad hoc network QoS architecture designed to be used in dynamic cooperative systems where several agents collaborate to achieve a common goal by accomplishing several tasks. Cooperation in a dynamic environment, implies that the agents have different needs in term of QoS according to their role and the data they send. DAN provides a differentiation for the traffic of agents into three classes: Urgent, Premium and Best-Effort. Each class is treated differently. Urgent class, used for sporadic messages, has the highest priority. Premium class, composed by data flows with QoS needs, requires a resource reservation in order to guarantee minimum delays and loss rates. DAN uses queuing and scheduling strategies to differentiate traffic, then it controls urgent and premium traffic rate. Moreover, it uses a hop-by-hop signalling to maintain a soft-sate and to reserve necessary resources for premium traffic.

Simulation results showed that, despite the mobility and the interference effect on the network performance, DAN respects class priorities and provides traffic requirements in terms of loss delay and loss rate for urgent and premium traffic.

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