QoS routing in ad hoc networks

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Abstract— **Technological advances and rapid development of the IEEE 802.11 standard have facilitated the growth of wireless local area networks (WLAN) and mobile computing. The throughput reached today by these networks (11 to 54 Mbits/s) allows to execute multimedia applications that require delay and throughput guarantees. Due to the bandwidth constraint and dynamic topology of Mobile Ad hoc NETworks (MANET), supporting Quality of Service (QoS) is a challenging task. A lot of research has been done on QoS in fixed networks (IntServ, RSVP or DiffServ) or wireless networks with access points (Mobile IP or UMTS), but most of them are not suitable for the MANET environment. This is due to the absence of centralized administration and the dynamic nature of network topology. The idea is then to support QoS at the routing level for such networks. For doing so, two approaches exist: the adaptation of the existing ad hoc routing protocols or the development of specific routing algorithms. This paper gives an outline on what is done in this field. We also propose a solution of QoS routing based on an extension of the AODV (Ad hoc One Demand Vector Distance) routing protocol. The proposed extension assumes the IEEE 802.11 DCF MAC layer as underlying technology.**

Keywords— ad hoc networks; QoS routing; AODV; IEEE 802.11.

I. INTRODUCTION

The increasing progress of the wireless local area networks (WLAN) has opened new horizons in the field of telecommunications especially with the appearance of commercial WiFi (Wireless Fidelity) products based on the IEEE 802.11b standard. Ad hoc networks can be distinguished from the other wireless networks by a total absence of fixed infrastructure and centralized administration. Ad hoc networks are established only with mobile stations free to connect themselves and to move in different directions. These networks know an increasing success due to their facility to be deployed and the savings they allow to make. A certain number of industrialists (Ericsson, IBM, Intel) and organizations (IEEE[1], ITU[2], IETF[3]) work in order to establish new standards allowing to support this kind of networks.

Throughputs reached today by MANET (Mobile Ad hoc NETworks) allow executing complex applications, such as multimedia applications (video conference, visiophony…), requiring guarantees on the throughput, the delay or the jitter. However these applications consume significant amount of resources and do not allow an efficient and fair use of the wireless channel especially when they coexist with data services characterized by bursts. A lot of work has been done in supporting QoS in the Internet, but none of them can be directly used in MANET. Considering the nodes mobility, their limited coverage and the absence of fixed and dedicated routers, new specific routing protocols integrating QoS must be so developed. These protocols must take into account the delay or bandwidth constraints on the selected routes. There are two possible approaches:

- An evaluation of the resources based on the MAC layer behavior. Routes are then computed according to the evaluated metrics. This approach is well adapted to deterministic access methods, like TDMA (Time Division Multiple Access), for which the available bandwidth corresponds to a relatively constant number of time slots during a whole transmission. For random access methods, like MACA (Multiple Access Collision Avoidance) [1] or CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) [2], the evaluation of the resources can be carried out by the exc hange of probes (beacons). Probes are specific packets charged to collect and forward delay or bandwidth information for a link or a route. The two major difficulties in this case are to minimize the overhead and to ensure the validity in time of these estimates;
- A service differentiation mechanism is implemented at the MAC layer [3]. This mechanism relies on station priorities, where, the routing protocol is responsible to assigning these priorities to the stations of the selected route. These priorities can be seen as a variation of the inter-frames spacing, of the waiting time after collision or of the frames length. This approach is well adapted to the random access methods, like MACA or CSMA/CA, for which a preliminary evaluation of the available resources is difficult. In this case, the QoS routing is not only considered as the search for a route with constraints, but more generally, within an entire QoS framework. However, when several streams with different QoS constraint cross the ad hoc network, the implementation of distinct priorities on a router node became complex to manage.

In this paper, we propose a solution to the QoS routing problem based on an extension of the AODV (Ad hoc One demand Vector Distance) [4] routing protocol. The proposed solution consists in tracing the routes in a reactive way by

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[1] Institute of Electrical and Electronics Engineers

[2] International Telecommunication Union

[3] Internet Engineering Task Force

taking into account QoS constraints for every crossed node. An estimate of the cumulative delay or the available bandwidth is successively made on every crossed node or every selected link assuming the IEEE 802.11 MAC DCF protocol [5] as underlying layer.

The rest of the paper is organized as follows. In section 2, we introduce the ad hoc routing issues. Section 3 describes the wireless QoS models. After a presentation of the main extensions and protocols of QoS routing in section 4, we describe our proposal to extend the AODV routing protocol based on IEEE 802.11 MAC layer in section 5. Finally we summarize the paper and give some suggestions for a future work.

II. AD HOC ROUTING

Addressing the layer 2 or 3 and consequently commutation or routing used by the wired networks are unsuited to the constraints of ad hoc networks[4]. Specific routing protocols are necessary to establish dynamically a route between two nodes and to maintain this route in spite of the unpredictable mobility of the nodes. Insofar as the ranges of emission and reception are limited, each node can play the role of a router to relay the communications between two distant nodes[5]. The choice of the routing algorithm is complex because of many parameters:

- Absence of centralization (distribution of routing information);
- Size of the network (evolutionary);
- Mobility, connectivity and topology;
- User traffic;
- Limited resources (CPU, memory, batteries…);
- Constraints of the low layers (unidirectional links);
- Multicast;
- Security;
- Quality of Service (QoS).

Ad hoc routing protocols fall into one of these three categories: proactive, reactive or hybrid [6]:

- The **proactive** or table-driven protocols that achieve a permanent evaluation of the routes in the network by periodic broadcasting of messages. We find in this category the «distance vector» and «link state» algorithms used in the fixed networks. DSDV (Destination Sequenced Distance Vector) [7] is a proactive protocol based on a distance vector algorithm; it uses the classical idea of the distributed Bellman-Ford algorithm (DBF). There are some other recent proactive protocols such as Optimized Link State Routing protocol (OLSR) [8] and Topology Broadcast Based on Reverse-Path Forwarding (TBRPF) [9] proposed in the IETF MANET working group.
- The **reactive** or on-demand protocols which initiate, on request only, a procedure of route discovery. For doing so, flooding search algorithms are used. AODV [4] is a reactive protocol which combines a route discovery on demand and a routing algorithm similar to the one proposed by DSDV.
- The **hybrid** protocols which combines the characteristics of the two types. The nodes keep in proactive way information of local topology and the routing is made according to a reactive technique. Zone Routing Protocol (ZRP) [10], Cluster Based Routing Protocol (CBRP) [11] are examples of hybrid protocols.

Other classifications can be made inside these categories [12]. We thus distinguish the protocols that introduce a hierarchy between the nodes (hierarchical protocols) from those, which give the same role to all the nodes (flat protocols). Moreover some protocols need information on the geographical localization of the nodes (Physical Location Information - PLI-based protocols).

III. QUALITY OF SERVICE

The quality of service in ad hoc networks can be introduced in several interdependent levels [13]:

- At the *medium access protocols (MAC) level*, by adding QoS functionalities to the MAC layer in order to offer guarantees [14];
- At the *routing protocols level*, by looking for more performing routes according to various criteria (in this study we are interested more particularly in this approach);
- At the *signaling level* with resources reservation mechanisms independent of the routing protocol. The QoS at the signaling layer is responsible for the coordination of the other QoS layers (MAC and routing) as well as other components, such as scheduling or admission control (cf. Figure 1).

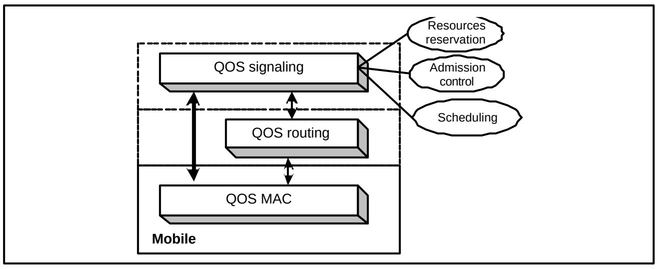

Figure 1. QoS Model.

The objective of the QoS routing is to determine a route with enough available resources to satisfy a request. The resources reservation on the optimum route, evaluated by the routing protocol, is generally done by the signaling layer. In addition, routing is necessary for the establishment of QoS on the signaling layer insofar as a reservation can fail if the resources are not available on a route or a link.

[4] Mobility, limited resources, fading effect, noisy channel, etc

[5] The use of several hops can be also a reduction factor of the necessary power to transmit to a distant point.

QoS on the MAC layer is an essential component of QoS support in an ad hoc network. The QoS components of the upper layers (routing and signaling) are dependent on, and coordinated with the MAC layer QoS protocol [15].

Several QoS metrics can be used for routing: the *delay*, the *throughput* and the *cost*[6]. Whatever selected metrics may be, mobility makes difficult the respect of the QoS constraints during a whole communication, and then, it is necessary to take into account the lifetime of the links. In addition, QoS models of fixed networks (based on IntServ, RSVP or DiffServ) are established on a certain number of constants such as stable topology, weak losses or a wide and extensible bandwidth and are not adapted to ad hoc networks constraints. Therefore, ad hoc routing protocols must be extended or modified to integrate QoS according to these different metrics.

IV. QOS ROUTING

The basic function of QoS routing is to find a network route that satisfies an end-to-end QoS metric. Quality of service is more difficult to guarantee in ad hoc networks than in other type of networks, because the wireless bandwidth is shared among adjacent nodes and the network topology changes as the nodes move. This requires extensive collaboration between nodes, both to establish the route and to ensure the necessary resources to provide QoS. The ability to provide QoS is heavily dependent on how well the resources are managed at the MAC layer. The QoS routing can be introduced in various manners:

- By developing specific protocols, possibly inspired by the wired world, and conceived basically to direct the routing following to the QoS constraints.
- From existing ad hoc routing protocols, by extending one of them with mechanisms allowing to differentiate routes according to the chosen metrics; the advantage of such solution is to avoid a systematic overhead when the QoS is not required.

Metrics can be defined on a path $P = i \rightarrow j \rightarrow \ldots k \rightarrow l$ by the following relations:

$$delay(P) = delay(i,j) + \ldots + delay(k,l)$$

$$BW(P) = \min \{BW(i,j),\ldots,BW(k,l)\}$$

$$cost(P) = cost(i,j) + \ldots + cost(k,l)$$

Among the proposed QoS routing algorithms, we distinguish a class of solutions called "*soft QoS*" [16]. The basic idea is that if the QoS is guaranteed as long as the path remains valid, it is possible to tolerate, according to the requirements of applications, transition periods corresponding to route reorganizations. During these periods, the traffic is best effort. In contrast, certain protocols are based on searching the route that maximizes the probability of respecting the QoS criteria [17].

[6] Number of hops, resources requested for each node, utilization ratio of the links, etc.

We summarize, below, the most promising works in this area. The two first ones belong to the *soft QoS* class and propose extensions to existing protocols, DSDV and AODV. In the two other works, the authors propose original approaches based on node hierarchy (Core Extraction Distributed Ad hoc Routing algorithm – CEDAR [17]), and on limited broadcasting of QoS probes (Ticket Based Probing – TBP [18]). The last paragraph gives a comparison of these protocols according to various criteria (metrics, overhead, link layer…).

A. *QoS routing on DSVD*

The proposed extension [19] is first intended to ensure QoS for real-time communications related to multimedia applications. A virtual circuit (VC) is established to transport these real-time streams only if the estimated bandwidth on the entire path is sufficient. If not, packets will be transmitted in a datagram mode. The protocol is based on TDMA transmissions. During a reservation request, the protocol estimates the available bandwidth on the main route supplied by DSDV and determines the number of free TDMA slots on each link throughout the path. The link bandwidth thus corresponds to the common free slots between two adjacent nodes. Consequently, the end-to-end bandwidth (the path bandwidth) can be evaluated gradually [20] taking into account the bandwidth on each link and the routing tables provided by DSDV. In the example given in Figure 2, if the node B can evaluate the available bandwidth towards A, C can use this information and the available bandwidth on the link towards B to calculate in its turn the available bandwidth towards A.

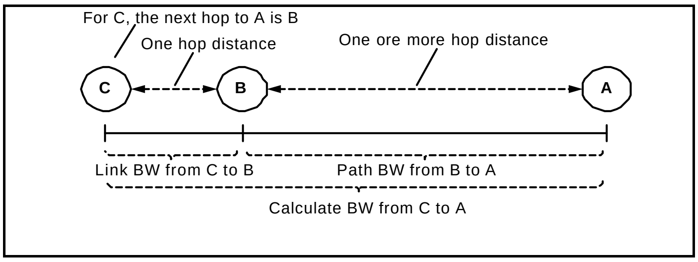

Figure 2. End-to-end bandwidth calculation.

DSDV being based on the calculation of the shortest path, the VC will correspond to the shortest route with the required minimum number of free slots for all links. The bandwidth information are integrated into DSDV routing tables and exchanged to calculate the end-to-end bandwidth on the shortest path between a source and a destination.

This extension based on the lower layers seems to obtain good results for the bandwidth evaluation but the algorithm used does not take into account the free slots evolution on different links (function of the inbound traffics and mobility). Moreover, the shortest route is not necessary the one that presents the best bandwidth. It is thus slightly adapted to very dynamic topologies presenting great stream variations and unequal amount of resources in the nodes.

B. QoS routing on AODV

This extension [21] also uses bandwidth metric and is based on TDMA slot management starting from what the source needs. Insofar as the associated routing protocol is reactive, the routes with QoS are established only on request. A measurement algorithm of the available bandwidth on the traced path is implemented and is coupled with the route search using RREQ (Route REQuest) packets of the AODV protocol. Each node is progressively able to determine the free slots to be used for a new stream. Free slots are evaluated for each node, according to slots occupied to send or receive with its neighbors.

We can thus define the set of free slots so that a node can transmit data without causing interferences to its receiving neighbors (SRT_i) as well as the set of free slots so that a node can receive without suffering interferences from its transmitting neighbors (SSR_i). In the illustrated example of Figure 3, each node has 2 slots s_1 and s_2. The current transmission between n_1 and n_2 is done on s_1. Consequently, nodes n_1 and n_2 cannot transmit or receive any more on s_1; n_3 cannot receive on s_1; n_4 cannot transmit on s_1.

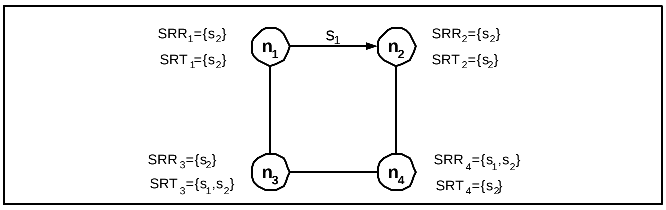

Figure 3. Example of TDMA slot selection.

From the sets SRT_i and SRR_i of the node n_i, it is possible to evaluate the number of free slots on the link towards the following node n_{i+1} of the path and consequently, for each link of the route. The end-to-end bandwidth is then gradually calculated according to an iterative algorithm taking into account the three closest links to a destination (considered as being sufficient to avoid the interference problems) and the bandwidth calculated for the two previous links. RREQ packets are then enriched with the bandwidth information. After evaluation of the end-to-end bandwidth, the destination node responds by sending a RREP (Route REPly) packet along the reverse path to reserve the slots up to the source.

The QoS routing protocol can also restore a route when it breaks due to some topological changes. Therefore it can handle some degree of network mobility. However, It works better in small networks (or over short routes) under low network mobility.

C. Core Extraction Distributed Ad hoc Routing algorithm (CEDAR)

CEDAR [17] is a QoS routing protocol based on the dynamic election of a stable network core formed by dominant nodes (called core nodes) from the topological point of view. The election of core nodes is achieved using beacons packets according to an algorithm making sure that all the nodes are either dominant or neighbor and minimizing the number of dominant nodes (cf. Figure 3).

The role of core nodes is to collect and propagate information about the available bandwidth on the links. Each core node thus maintains a table on its local topology and on the distant links state in terms of stability and minimum bandwidth. According to preset thresholds, every increase or decrease of the bandwidth (BW) measured on a link by a node must be notified to its dominant. Then, the dominant node makes a broadcasting towards the core by indicating the concerned link and the direction of variation. The dominant nodes must also ensure routing according to a reactive protocol.

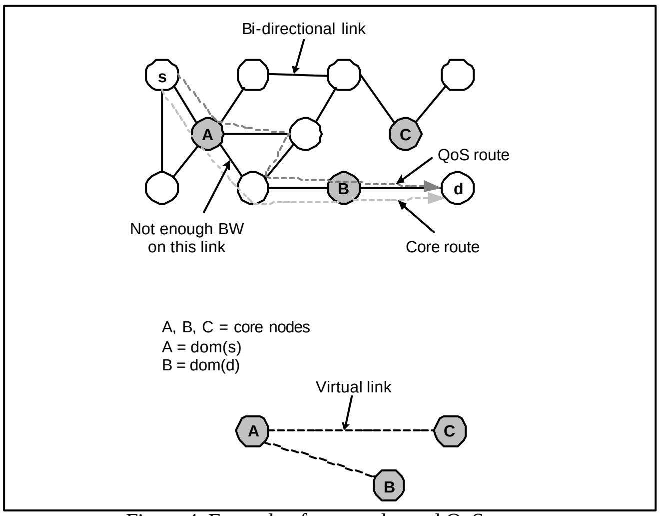

Figure 4. Example of core nodes and QoS route.

As shown in Figure 4, the QoS route is established in two steps:

- Discovering a core route by the dominant nodes using the associated routing protocol;
- Search for the QoS route based on the core route.

In case of link failure, two mechanisms are processed in parallel:

- Dynamic search for a possible temporary route in the breaking point neighborhood;
- Notifying the source which starts back a complete search for a new QoS route.

CEDAR is based on CSMA/CA medium access protocol which must be able to estimate the available bandwidth on the links. The routes obtained are optimized in terms of bandwidth and of number of hops but in case of core failure, the routing is stopped for a transition period which can involve packets losses.

D. Ticket Based Probing (TBP)

In TBP [18], each node maintains, using periodic transmission of signaling packets, a local state (delay, bandwidth, cost…) for all links towards its immediate neighbors. It uses a broadcast of limited discovery route requests to avoid the overheads caused by a global flooding. During a search for a route, the source sends probe packets with a limited number N_0 of tickets. A ticket corresponds to a searched route and a probe contains at least one ticket (the number of searched routes is limited by the number of tickets). The choice of N_0 is done at the source and is based on QoS constraints (delay or bandwidth) and on local state information (for a significant required delay, a single ticket can be enough). The intermediate nodes propagate the probes by distributing the tickets according to their local states (for a delay constraint, a node will send more tickets on a fast link). Generally, the more constraints a data stream will have, the more tickets will be associated to the corresponding request.

In the example of Figure 5, two probes p_1 and p_2 are sent starting from s. The first contains one ticket, the second two. At node j, the probe p_2 is split into two probes p_3 and p_4 containing each one a ticket. There are at most three probes at any time and three paths are found: s $\rightarrow$ i $\rightarrow$ d; s $\rightarrow$ j $\rightarrow$ d and s $\rightarrow$ j $\rightarrow$ k $\rightarrow$ d.

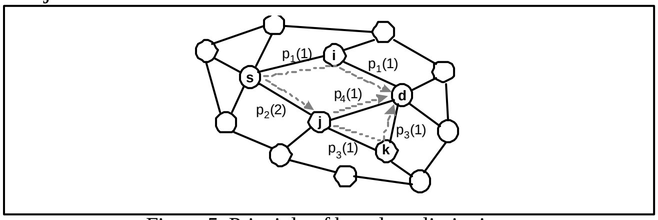

Figure 5. Principle of broadcast limitation.

Routes are memorized by probes and once the choice of a primary route by the destination (that of a better QoS) done, a confirmation message is sent back to the source for reservation. In order to increase the probability of finding a route, two ticket types are used: the yellow tickets for searching a path in respect with the imposed constraint and the green tickets to obtain the low cost solution.

In spite of the fact that the nodes only know their immediate neighborhood, TBP is efficient because it allows finding routes with a probability close to the flooding algorithms. TBP has been conceived for networks in which mobility is sufficiently low (like in a conference room for example). The lifetime of the routes must be important according to the necessary time for establish or restore a route. Besides, the MAC layer and the resources evaluation techniques are not defined.

E. Performances comparison

The table below summarizes the characteristics and the performances of the existing solutions, presented above, to provide quality of service at the routing layer in ad hoc networks.

TABLE I. COMPARISON OF QOS SOLUTIONS.

	QoS on DSDV	QoS on A AODV	CEDAR	TBP
Approach	Proactive	Reactive	Reactive	Reactive
Table maintenance	Yes	Yes	Yes	Yes
Multipath	No	No	No	Yes
Link layer	TDMA	TDMA	CSMA/CA	Not defined
Metrics	BW	BW	BW	Delay, BW, cost
Evaluation of the metric	Yes	Yes	No	No
QoS overhead	Low	Medium	High	Low
Mobility	Low	Low	Medium	Low
Density	Medium	Medium	Medium	Low

The first three solutions are based on the resources evaluation and reservation, considering a specific MAC layer (TDMA multiplexing, CSMA/CA access method). Only TBP proposes a multi-criterion QoS solution but does not gives any indication on the measurement of the used metrics. Besides, all these proposals are provided for not very dense networks and low mobility scenarios.

V. QOS EXTENSION FOR AODV ON 802.11

In the following we present the proposed QoS routing solution based on the AODV routing protocol and considering the IEEE 802.11 DCF MAC protocol as underlying layer. Our proposal uses two metrics the delay and the bandwidth. The QoS route is traced node by node using AODV [22]. For each crossed node, an estimate is made to know whether the maximum delay or minimum bandwidth requirements could be satisfied. If not, i.e. in the case where the delay estimate remains too long at an intermediate node or the bandwidth too weak on a taken link, the route search will be interrupted. The QoS routing thus remains reactive and uses only extensions on the AODV request (RREQ) and reply packets (RREP).

A. Delay estimation

The delay estimate uses one of the AODV parameters: the NODE_TRAVERSAL_TIME (NTT), initially considered as a constant [4]. Here, the NTT becomes an estimate of the average traversal time of a packet for one hop and includes the transmission delay over the link and the processing time in the node (delays in queues, processes interruption time, etc).

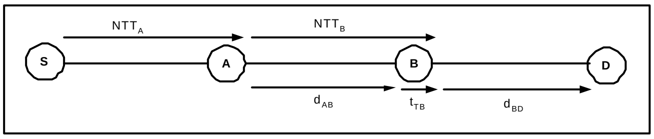

Figure 6. Successive estimations of NTT.

In the example of Figure 6, we obtain for the node B:

$$NTT_B = d_{AB} + t_{TB}.$$

The processing time in the node (t_{TB}) can be considered as a specific constant to each node; the transmission delay between the two nodes[7] (d_{AB}) corresponds to the time between the moment the packet is transmitted to the MAC layer by the source node and the moment the acknowledgement is transmitted by the destination node:

$$d_{AB} = T_{ACK} - T_{transmission}$$

If the clocks are synchronized between nodes, the measurement of d_{AB} can be made by the transmission of route request (RREQ) and route reply (RREP) packets provided

[7] On a 802.11 network, this delay is function of the contention and the possible retransmissions due to collisions; the durations of frames transmission (RTS, CTS, data, ACK); the inter-frames spacing (DIFS, SIFS) and various propagation delays.

with temporal extensions (timestamps) according to a format specified in NTP [23]. Note that the node clocks can be synchronized using NTP.

The measured delay d_{AB} being related to the packet size, a correction should be made to take into account an average size instead of the RREQ or RREP packets length used for measurement.

Insofar as route delays depend on unpredictable events (movements, arrivals, extinctions, variations of streams and traffics, etc.) occurring at various layers, the variance of the node-to-node delays can be significant. To take into account these variations in time, the two current methods [24] are based on the calculation of an average on a fixed size window and the use of the previous measures with an average weighted by a forgetting factor (*exponential forgetting*). To limit the overhead, we retain the second method, which gives the delay between nodes A and B as follows:

$$d_{AB}(t)=(1-l)\sum_{k=0}^{\infty} l^{k} . d_{AB}(t-k)$$

Where $l \in [0,1]$ is the forgetting factor.

B. Bandwidth estimation

The bandwidth estimate on a link between a source and a destination can be formulated as in [25] by:

$$BW_{available} = (1- u) \times Throughput_{on\ the\ link}$$

Where u is a rate representing the link utilization. To calculate the available bandwidth for a node, the throughput on a link must be evaluated initially. A first evaluation can be done simply by emitting packets and measuring the corresponding delays:

$$Throughput_{packet} = \frac{S}{T_{ACK} - T_{transmission}}$$

S being the size of the packet, $T_{transmission}$ the packet-transmission moment measured on the network layer, and T_{ACK} the acknowledgement-reception moment. To limit the influence of the packet size, a simple solution consists in subtracting from delay a constant related to the overhead of the packets and taking account of the characteristics of the IEEE 802.11 link.

As for the delay estimation, it is necessary to limit the random aspect of the measurement by one of the two methods previously evoked. In the case of the use of a transmission window of n packets [25], the measurement of the window duration and the idle time for the n transmission on the link make possible the evaluation of the link utilization ratio. Consequently, the available bandwidth is calculated with this ratio and the average measured throughput for the n transmitted packets as follows:

$$BW_{available} = \frac{idle\ \ time}{windows\ duration} \times measuredthroughpu$$

C. Routing

For each route entry corresponding to each destination, the following fields are added to the routing tables:

- Maximum delay;
- Minimum available bandwidth;
- List of sources requesting delay guarantees (with the requested delay);
- List of sources requesting bandwidth guarantees (with the requested bandwidth).

An extension is foreseen by AODV for its main packets RREP and RREQ [4].

8 bits	8 bits	n bits
Type	Length	Type-specific data…

Figure 7. AODV Extension format.

A "delay" extension has two meanings according to the packet type:

- For an RREQ packet, it indicates the allowed delay for a transmission between the source (or an intermediate node forwarding the RREQ) and the destination;
- For an RREP packet, it gives an estimate of the cumulated delay between an intermediate node forwarding the RREP and the destination.

A node with maximum delay constraints thus transmits a RREQ packet with a QoS delay extension. Before forwarding an RREQ packet, an intermediate node compares its NODE_TRAVERSAL_TIME with the remaining delay bound indicated in the extension. If the delay bound is inferior, the packet is discarded and the process stops. Otherwise, the node subtracts its NTT from the delay bound provided in the extension and continues to propagate the RREQ as specified in AODV (cf. Figure 7).

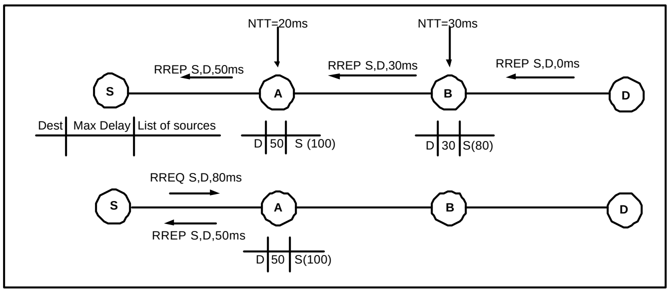

Figure 8. Example of QoS delay request.

In response to a QoS request RREQ (cf. Figure 8), the destination sends an RREP packet with a null initial delay (and a "timestamp" extension for the delay measurement). Each intermediate node adds its own NTT to the delay field and records this value in the routing table for the concerned destination before forwarding the RREP. This entry update allows an intermediate node to answer the next RREQ simply by comparing the maximum delay fields of the table with the value of the transmitted extension.

For a "bandwidth" extension, the principle remains approximately the same. A node with a bandwidth constraint transmits an RREQ packet with a QoS bandwidth extension, which indicates the minimum bandwidth which must be available on the whole path between the source and the destination. Before forwarding the RREQ packet, an intermediate node compares its available bandwidth to the bandwidth field indicated in the extension. If the bandwidth required is not available, the packet is discarded and the process stops. In response to a QoS request RREQ, the destination sends a RREP packet with an infinite initial minimum bandwidth. Each intermediate node which forwards the RREP compares the bandwidth field of the extension with its own available bandwidth and keeps the minimum between those two values to propagate the RREP. This value is also recorded in the routing table for the concerned destination. It indicates the minimum available bandwidth for the destination.

If the QoS request concerns both delay and bandwidth, the two extensions can be appended to the same request and reply packets. In this case, the two mechanisms of request and reply will be applied simultaneously. The request packets will be discarded if one of the constraints cannot be satisfied.

A specific RREP packet with a "Delay_increase" or/and "Bandwidth_decrease" extension is generated when an intermediate node detects an increase in its NTT or/and a decrease in its available bandwidth that does not allow any more to guarantee the QoS initially required by a source. As the nodes have recorded in the routing table the address of the sources asking for guarantees, as well as the values of the requested delays and bandwidths, RREP packets will be transmitted to all the stored sources suitable to be affected by a delay or a bandwidth changes detected on the node (cf. Figure 9).

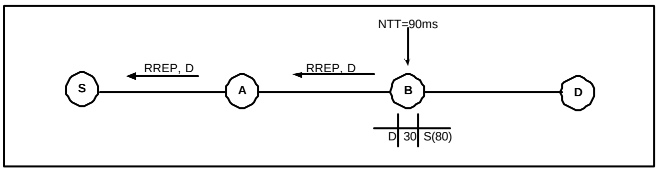

Figure 9. Example of QoS delay lost.

VI. CONCLUSION

As stated at the beginning of the paper, if we consider that QoS routing relies on the MAC layer behavior, two approaches can be possible:

- The evaluation of resources based on the MAC layer behavior. Thus, routes are traced according to the evaluated metrics;
- A service differentiation mechanism is implemented at the MAC layer to assign priorities to the stations of the route selected by the routing protocol.

Among the related works presented and based on the first approach, only CEDAR and TBP can be established on an 802.11 network. Considering the overhead caused by the election of dominant nodes and the validity in the time of those, CEDAR is only suitable for dense and stable networks. The limited broadcasting technique used in TBP is successful for low mobility networks. For these two protocols no method of metrics estimation is considered

The solution we propose, also based on the first approach, preserves the reactive nature of AODV. The overhead due to QoS extensions on the route search packets remains weak. The evaluation of the resources remains a complex problem on an ad hoc network based on an 802.11 MAC layer. At the moment, this work is still progressing toward complete simulation study to test and improve the proposed solution. A compromise between the overhead, the validity in time and the precision of measurements must be found and is the object of a near future work.

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