ROUTING PATTERN SELECTION FOR OPPORTUNISTIC NETWORK MANAGEMENT

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ABSTRACT

This presentation provides elements of protocol description of ad hoc network traffic flows route set up adaptation. These elements enhance the communication capabilities of self-organized networks. The protocol presented detects topological situation communication on which throughput optimisations may be applied. This presentation focuses on multi-flows network coding optimization. It describes the different stages of the protocol to catch and to transfer to the nodes initiating traffic flows the information needed to adapt the traffic path in order to apply network coding optimizations. The novelty of the approach is to combine "classical" ad-hoc routing protocol and network coding optimization in reasoning in terms of independent multi-flows (some of them being potentially established) routes co-determination, instead of single traffic route determination. The protocol is first illustrated on a butterfly topology. In a following section, its application is described on bi-directional flows, with specific description on the data packets coding and decoding phases application for these kinds of topologies. The definition of delegated ingress and egress nodes is presented to extend the topologies set the protocol may be applied. Determination of multi routes optimization is also presented.

1. INTRODUCTION

Opportunistic networks address the inter networks communication between operator network infrastructure and decentralized dynamic self organized networks (SON). This communication encompasses the particular class of Mobile Ad-Hoc Network (MANET) widely present on Private Mobile Radio (PMRs) and military networks configuration.

In the general case of opportunistic networks, and more particularly on the scenario description described in [1], these scenarios integrate (even if most of the networks description are operator governed) self-organizing network whose management is similar to the one of MANET networks.

The issues to be raised in terms of routing enhancement are manifold. One of these issues is the Quality of Service management, and in particular the routing based throughput optimization including resource allocation optimization.

Algorithms have been proposed in the 2000's to optimize routing protocols for the specific mobile networks, proactive OLSR, OLSRv2 [2], [3], reactive AODV, DYMO [4], [5]. FEQMM [6], SWAN [7], QOLSR [8] and CEQMM [9] extensions integrate to these protocols a quality of Service management to maintain and adapt a QoS of established traffics. These extensions mainly focus on an adaptation of resources provision, applying QoS metrics for the route path selection [8], combining both per-flow state property of IntServ for highest priority flows, and service differentiation of DiffServ for lowest priority flows [6], [9], or applying an explicit congestion notification from a rate control mechanism to dynamically regulate admitted real time traffic[7].

We propose in this paper protocol elements which complete these optimizations. This protocol focuses on gains that may be provided by the specific characteristics of these kind of networks: decentralized management of resources allocation, self traffic flows route (re)configuration including broadcast and multi-route establishment, and opportunities due to node mobility. The proposed algorithm combines the (re)routing of traffic flows on ad-hoc network with a throughput optimization technique called network coding. This optimization technique proposes to use the common routing paths of multi-flows to reduce the information to transmit on these path, benefiting by the information transmitted on other paths for these flows.

The context of opportunistic network is provided in section II. The principle of network coding is described in section III. Issues on the application of network coding is illustrated on one example in section IV. The proposed protocol steps to solve the issues are described in section V, illustrated on the butterfly (or Manhattan 2x3) topology. Definition of delegated nodes, and application on multi paths optimization are given in section VI. Specific application on 2 sides flows is given in section VII . Conclusion and future work are given in section VIII.

2. CONTEXT OF THE STUDY

Opportunistic Networks (ONs) are temporary, localized network segments that are created under certain circumstances. According to that vision, ONs are mainly governed by the radio access point (AP) operator, and they can be considered as coordinated extensions of the infrastructure network. ONs comprise both infrastructure and infrastructure-less sub networks. This coordination requirement is the object of a current standardization to the ETSI RRS [10] in terms of interface definition, and messages exchange between the APs and infrastructure-less (ad-hoc) devices. This standardization integrates cognitive radio capabilities and physical layer allocations (radio resources allocation) monitored from L2/L3 layers.

The work presented in this paper contributes on the optimization of the communications of SON part of the ON. It is based on the study on scenarios of the infrastructure less devices part of the opportunistic network. The typical scenarios scheme is the concurrent traffic flows of such nodes to the AP-SON relay nodes.

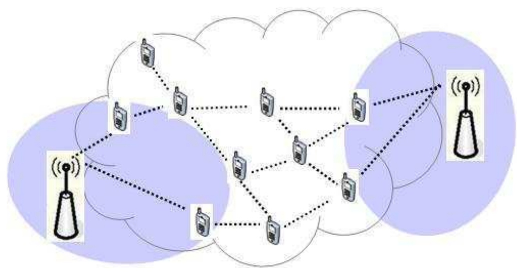

Figure 1: Scenario on the SON part of ON

This scenario gets explicit the needs of protocol between nodes the SON part of the ON. The study described in this paper proposes solutions to optimize the throughput of the data flow exchange by the combination of ad-hoc routing pattern selection and the network coding optimization.

3. PRINCIPLES OF NETWORK CODING

The concept of *network coding* was first introduced for satellite communication networks in Yeung and Zhang [11] and then fully developed in Ahlswede et al. [12].

The principle of network coding is described in the following picture, applied on the butterfly topology. This picture presents two traffic flows, one from S_1 to D and F, the other one from S_2 to D and F. Moreover each one of the common egress node may receive from one path one of the traffic flow, and from one part of one another path (which may be restricted to only one node), the two traffics are relayed using the same relaying nodes resource. The principle is to code the two traffic flows with a common smaller one, using a coding function *Nc()*, the traffic flow relevant from this flow being decoded by the use of the other flows already received. In the example the coding function is the bitstream *xor* of the two flows (considered of numbered packets of the same size). In D(resp.F), receiving X1 (resp.X2) and X1 or X2, it easily deduces X2 (resp. X1).

The figure 2 shows the differences between the use of network coding and a classical independent flow route allocation. The gain in terms of throughput and number of message sent between the two alternatives are of 1/3 (from 6 emission to 4), with means also a gain in radio resources and in power consumption in the relay nodes. In particular in the first situation the node E receives two packets and sends two packets (and causes a bottleneck in the flows, impacting the QoS) whereas in the second one, it receives and sends only one packet (with a more homogeneous traffic load between the nodes in the topology) .

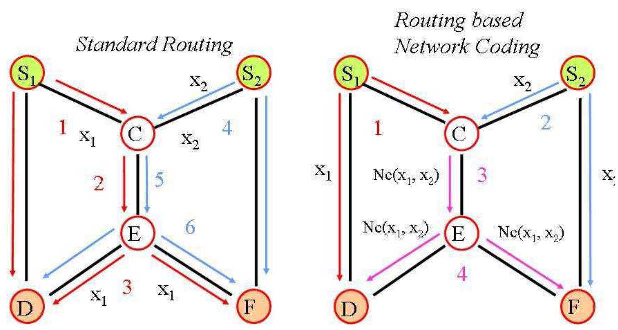

Figure 2: Network coding principle from the butterfly topology

The figure 3 presents the application of the network coding optimization on a 2 sides flow relay topology. The optimization in terms of throughput is of 2N/(N+1) [13], with N as number of relay nodes. The examples provided present network 2 inter-flows coding optimizations. The principles presented in this paper may be extended to n-flows optimization, with *Nc()* defined as a linear combination of n flows..

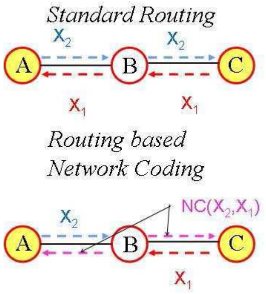

Figure 3: Network coding principle from the 2 sides flows relay topology

4. RATIONALE ON A CONCRETE EXAMPLE

The following figure presents the issue to be solved on the butterfly (or Manhattan 2x3) topology as presented previously in the network coding description. In this example a flow X1 is already established from the ingress S1 to the egress D and F. The traffic route (which is optimal) is established with respect to the path S1-D-E-F. A new flow is requested from the ingress S2 to the same egress nodes D and F.

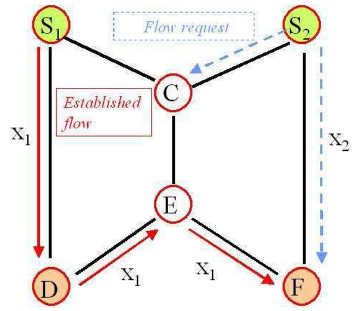

Figure 4: Routing path application example

The figure 5 describes a potential routing path definition using a "classical" routing algorithm (called Routing X) which allows to optimize the flow paths, independently from one to each other, or more precisely not modifying current flow established in the new flow route determination. An example of such a flow route defined is presented, and compared with the optimal route, using the full power of network coding optimization.

As shown in figure 6, to go from the first routing situation (routing X) to the second one (routing based NC), the following operations need to be applied: 1) link cut on the X1 flow on D-E and E-F; 2) X1 multicast at node S1 to C and D; 3) coding decision on node C; 4) relay of the coded flow from the node E to the nodes D and F; 5) decoding decision on the egress nodes D and F. These modifications are illustrated on figure 6.

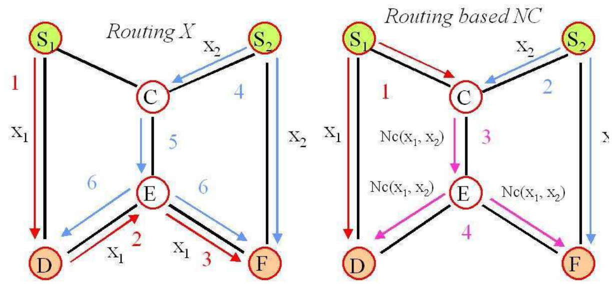

Figure 5: Comparison between a classical routing and a routing based NC

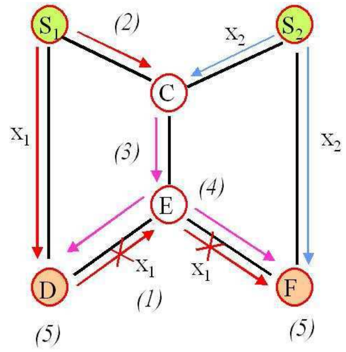

Figure 6: Modifications to be applied to go from Routing X to Routing based NC

The issue to solve remains to collect at a node the information needed to define a decision of network coding. These information are in one hand a knowledge of the topology close to this node, and in the other hand the information of flows on this topology. Note that these flows can be not relaying through this node (as shown in the example in figure 6 on node C for the flow X_1).

The algorithm described in the following section proposes to generalize the modification to be applied on existing established flows in order to optimize the flows in using the network coding flows optimization capabilities.

5. PROTOCOL STEPS DESCRIPTION

In order to illustrate the protocol steps, we will take the classical routing flows situation described in figure 5 as starting situation the algorithm will be applied.

Flooding of traffic route information over the network

The first work will be applied to each traffic flow. It consists on the memorization, for each node in the neighborhood of a traffic path coming from the ingress node, of the distance in a number of nodes to the traffic ingress, and of the precedent nodes identifier to access to this originator ingress node.

This first step can be done on a bounded distance Dijkstra algorithm [14]. The selection of short paths to the ingress node traffic can be considered as a restriction, to restrict the flooding to n-hops distance, potentially dependant on quality of service requirements such as latency. The application on our example is shown on *Figure 7*, on a 3 hop bounded flooding exploration.

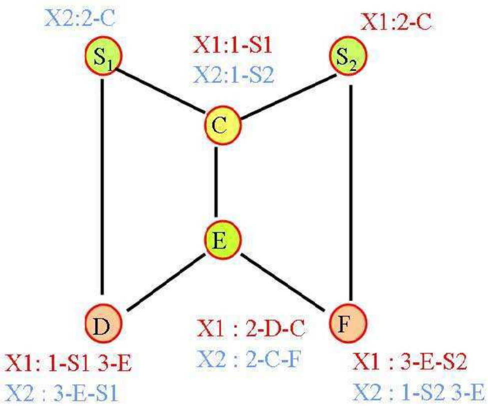

Figure 7: Step One

Detection from egress nodes of potentially "pivot" nodes candidates.

This step consists, periodically from candidate egress nodes by sending specific messages, to send information on these flows. These messages, called Mtopo messages contain the following fields:

- a **Lf** flows list,
- a **Lp** list of list of optimisable flows with network coding
- a **Firstcod** list of the first node identifier the network coding may be applied, and the distance **Ldp** of the path the network coding will be applied,
- a **Nd** list of egress nodes,
- a **Ln** list encoding the tree of the paths explored,
- a **Lft** list indicates, for each path of the Ln tree the flow id of path including the ingress node of the flow.

In the next figures  represents Mtopo messages.

As illustrated in *Figure 8*, a node (in the example the node E) receiving such message from different egress node has the sufficient information to determine if it can be such a potential "pivot" node. The egress nodes that can send such messages are nodes egress of several flows.

Messages relay from potential "pivot nodes".

The pivot node identification is "pushed" to the nodes that potentially transfer the (in the example 2) flows.

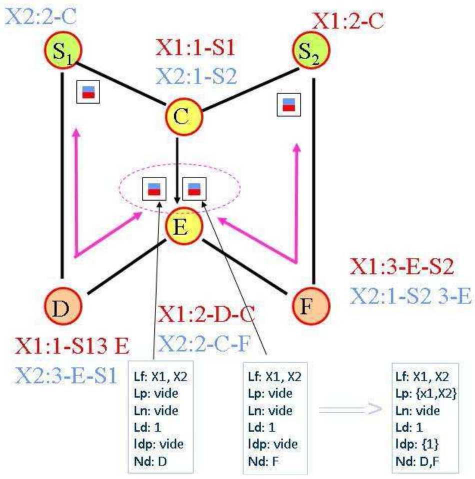

Figure 8: Step 2

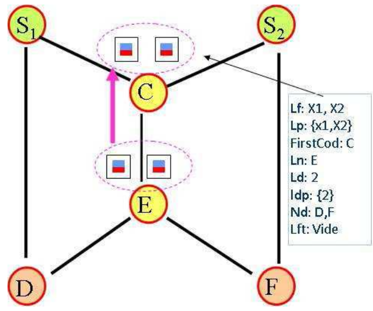

Figure 9: Step 3

Decision function on ingress nodes

The messages are finally sent to the ingress nodes. From the information received from the different paths of these information, network coding is applicable only if one path is common with an other flow (i.e. with a message coming from a node identified as a potential network coding pivot node) and one another. The network coding decision will be applied taking care of the different constraint required for the traffic flow (latency, resource allocation capabilities, link stability). In case of network coding application decision, the flow is reinitiated with the information of network coding application sent to the respect nodes). The network coding is actually applied on a "pivot" candidate node if the node receive information from the two originator nodes. Protocol between the ingress nodes and the pivot node may be defined to know if the ingress nodes decide or not to apply network coding.

The Mtopo messages transmitting to the ingress nodes provides the sufficient information to detect the topology information to decide if a network coding is applicable.

In the example, the ingress node S1 (resp. S1) has the knowledge:
- of a path S1-D (S2-F) the traffic flow X1(resp.X2) may be transmitted
- of a tree S1-C-E-D;F the flows X1 and X2 may be transmitted, with a 2 nodes encoding of the two flows from the node C.
- of a path transmitting the X2 (resp.X1) flow from the ingress node to the egress node F (resp.D).

The S1 and S2 nodes have the sufficient information to (re)establish the optimal traffic routes as depicted in figure 5 and labeled "Routing based NC".

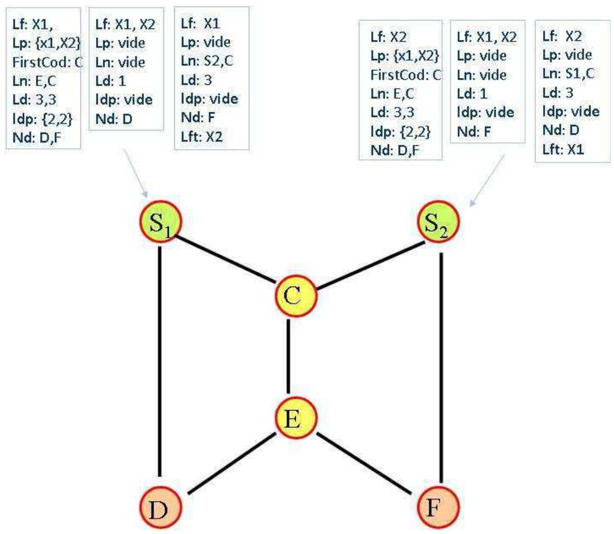

Figure 10:Step 4

Traffic paths re-establishment

The fifth step is the network coding application on common path and decoding on the egress nodes. The ingress nodes assign the route establishment in transmitting to the next hop nodes of the traffic path defined, MEstab messages including:
- the flow identifier, and any other parameters needed to initiate the traffic
- flows coding authorization, with the flows identifiers
- the first node identifier the coding will be applied
- the nodes tree to access to the egress nodes.

Each node receiving the MEstab message:
- allocate the resources needed to kinitiate the traffic,
- suppress its id in the nodes tree
- transfer the message to the neigbour nodes of the tree

If the first node identifier the coding will be applied is the current node, the node memorize the information and will proceed the coding of the flows at the receipt of packets of the flows.

6. DELEGATED NODES AND MULTI PATHS OPTIMIZATION

The algorithm presented in section 5, is restricted to the ingress nodes from originator of independent paths. The ingress nodes are also restricted to ingress nodes of several traffics. The following figure introduce the notion of :

- delegated ingress nodes, on with the capability to stamp the **Lft** field of the MTopo messages is delegated.
- delegated egress nodes, on which the capability to send the MTopo messages are delegated (in the following figure we suppose the node F is the ingress node of the traffic flow X2).

The definition of the set of delegated ingress and egress nodes is the object of future work.

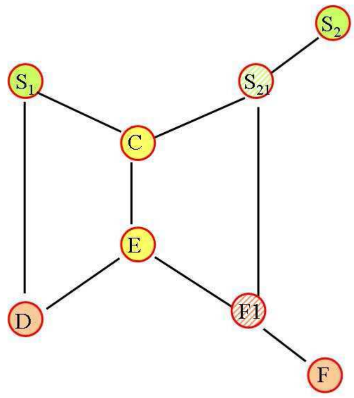

Figure 11: ingress and egress delegated nodes

The Decision function on ingress nodes may define the paths the network coding is applicable. One solution is to deterministically select one of the path (for example from an ordered function from the identifier of the coding nodes candidates). The other solution is to use the opportunity of these paths to transmit several flows from these paths.

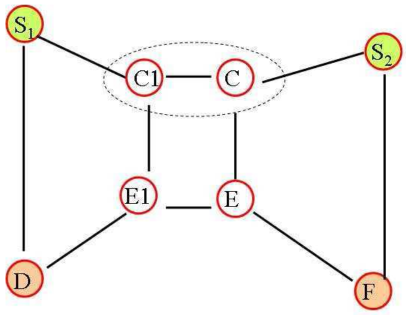

Figure 12*: multi paths optimization determination*

7. APPLICATION ON 2 SIDES RELAY TOPOLOGY

This section describes the application of the proposed protocol on a 2 sides flow relay topology. Practically, this topology is the one of PMR vehicles running along a road.

The particularities of these particular topologies re the following:

- The ingress node of a flow is also the egress node of this flow. These nodes are considered as both initial and egress nodes.
- The relay nodes have to encode and decode the data at each data packet receipt, these decodings are applied with respect to the data packets previously received.

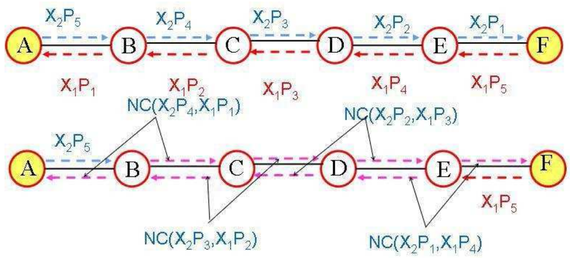

Figure 13:2 bi-directional flows with 4 relay nodes with standard routing and network based routing

The algorithm based on MTopo message transmission from egress node to ingress nodes is applied, with a specific field indicating the flows are bi-directional, as illustrated in figure 14.

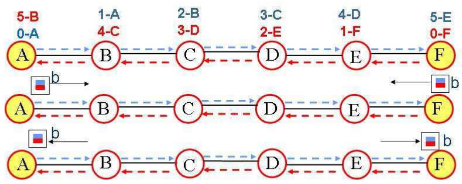

Figure 14: MTopo messages go through within the network

When receiving MTopo messages from the two egress nodes, the relay nodes allocate resources to memorize 2 packets of the two flows (as shown in figure 15).

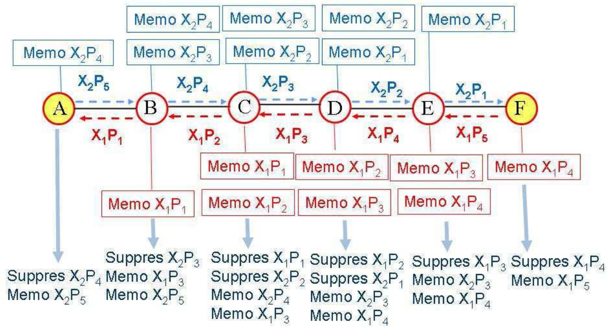

Figure 15: First step of memorization after recept of the mTopos messages from both sides for each node

The ingress nodes, at receipt of the Mtopo messages, transmit Mestablish nodes, with the next hop as first hop realizing the coding. The particularity of the coding /decoding process is that each relay node encodes and decodes the data packet The dissemination of the coding encoding steps from the first encoding nodes to the others is illustrated in the figures 16 and 17.

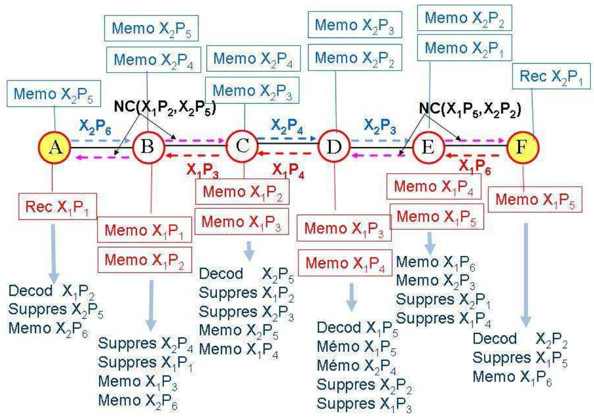

Figure 16: The relay nodes close to the in/ingress nodes are the last to receive the MTopo messages, all the other are ready to decode the data they encode, from MEstab message from e/egress nodes

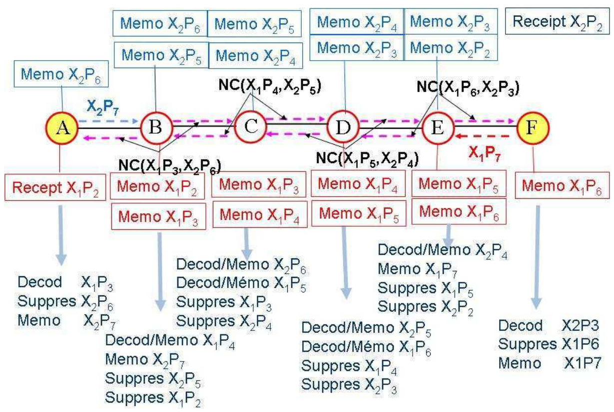

Figure 17: nominal situation, all nodes coding and decoding packets received.

8. CONCLUSION AND FUTURE WORK

This paper presented protocol elements which combine "classical" ad-hoc routing protocol and network coding optimization in reasoning in terms of independent multi-flows (some of them being potentially established) routes co-determination, instead of single traffic route determination. This protocol offers the capability to catch the information needed in terms of topology and flows in order to decide at the ingress node level the best routes to benefit of network coding capabilities. Adaptation to particular topologies and traffic flows were explored, with the extensions to 1) multi-paths optimization determination, 2) application on the specific case of 2 flows bidirectional flows and 3) the definition of delegated ingress and egress nodes to extend the set of topologies the protocol may be applied. Simulations are currently under development to evaluate the process described on different topologies and flows situations. First future work is the assessment of the proposed protocol from these simulations. Other work planned in the future is the further exploration of the proposed extensions.

9. ACKNOWLEDGMENT

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