A first study on video transmission over a nanowireless network

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ABSTRACT

Video streaming is a growing application on the Internet, and its growing pace is not slowing down. There have been a tremendous amount of work on video streaming over the Internet but nobody has ever studied in detail video streaming over a nano-wireless network. We think that video streaming could be a potential application for nano-wireless networks and we know that video streaming is a challenging application for networks. First, video streaming is a real-time transmission meaning that it is sensitive to delay and jitter. Second, it is often better not to retransmit losses to avoid video freezing. That is why nano-wireless layers will probably have to be tuned for video streaming.

This article studies, through simulation, different scenarios of video transmission over a nanowireless network. We conclude that research needs better tools and models for such studies.

General Terms

Simulation

Keywords

video streaming, nano-wireless communications, simulation

1. INTRODUCTION

According to the last Sandvine report [1], in North America, the video streaming in fixed internet connections uses 50% of the downstream bandwidth, far before the next usage which is HTTP with 10% of the downstream bandwidth. This trend on video streaming predominance can also be seen for the mobile access. The first usage of downstream bandwidth on mobiles is for YouTube with 18% but if we sum up all video usages (YouTube, MPEG, Netflix) we reach 31%. This trend is also true for Europe, South America and Asia but to lesser extent. This shows that video streaming has became the first usage within the Internet.

The Internet of Things (IoT) [5] federates the things that need to communicate and their requirements are different from traditional computers and humans. Some things will still need a high bandwidth and a low latency but most of them only need low power communications and, low bandwidth and high latency are not an issue. IoT is therefore growing both inside and aside from the Internet creating a new way to communicate.

Advances in micro-electro-mechanical-systems (MEMS) are enabling the design and fabrication of distributed intelligent MEMS (DiMEMS) [10]. A node in a DiMEMS system is basically composed of actuators, sensors, a processing unit and communication capabilities, which makes it a micro-robot integrated in a much larger ensemble, the IoT.

The appearance of nano-electromagnetic communications, referred to as nano-wireless in the rest of this article, changed the perspectives for communicating between small things, making possible communications between miniaturized elements, with the internet of micro-things [9], or even smaller elements, with the internet of nano-things [18]. Nano-wireless communications have been first proposed in [3], later detailed in [4] using graphene nano-antennas and been used in some micro-robot applications [8]. As these antennas are very small they are able to radiate in the terahertz band.

Video streaming is therefore possible between very small things but remains complex due to the nature of Terahertz band. Propositions have been made for defining an energy-efficient physical layer [25] but transmitting video on top of these different layers is still an open issue (but has been studied in ultra-wide band networks in [11]). In fact, we think that a cross-layer approach is needed in the design of the communication layers of nano-wireless communica-

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tions. This means that applications have to be proposed and tested. In a previous work [7], we have studied the integration of wireless capabilities in micro-robots of the Claytronics project, showing the enhancement created by wireless communications, but not using nano-wireless communications yet. Also, video streaming at small scale is of importance in many fields, e.g. biological, defense and security, under the assumption that tiny cameras could eventually be embedded in the environment (wall, body etc.)

This article is at the conjunction of these four research fields: micro-robots, IoT, nano-wireless communications and video streaming, and presents a preliminary study on the possibility to stream video between micro-robots viewed as IoT elements and using nano-wireless communications. The objective is to learn some lessons on the efficiency of the current nano-wireless physical layer in order to enhance it afterwards. We use two NS3 plugins: Nano-Sim, to simulate the nano-wireless physical layer, and Quality-of-Experience (QoE) Monitor, allowing to stream real video sequences inside NS3 and to evaluate the result in terms of video quality.

2. CONTEXT

2.1 Nano-wireless communications

The first idea of nano-wireless communications was presented in [3]. This article defines the different kinds of nanonetworks media (nanomechanical, acoustic, electromagnetic and chemical or molecular) and defines the nanomachines in a similar way to Berlin in [6] but extended to a bio-hybrid approach. In this article, the molecular communication is preferred to as the electromagnetic one. In following articles, Jornet, Akyildiz and al. present the concept of CNT-based nano-antennas in [17] together with a first attempt to define its characteristics [2]. In [14], a model of path loss is proposed using HIgh resolution TRANsmission molecular absorption database (HITRAN). The noise, in the terahertz band, is mainly introduced by the molecular noise created by the absorption of the signal which is exciting molecules. That is why short pulses should be preferred for transmitting information. These conclusions are confirmed and more detailed in [15]. In the mean time, the idea of nano-wireless sensor networks is investigated in [4] giving a first view of possible hardware and potential applications. Given that short pulses would give better results, a new communication scheme called Time Spread On-Off Keying (TS-OOK) is introduced in [16]. TS-OOK uses very short pulses in the range of femtoseconds where each pulse transmits a "1" and the absence of pulse transmits a "0" which is called on-off keying. Pulses have to be transmitted using a period of time much bigger than the duration of a pulse. This ensures an efficient medium sharing as well as reducing the possible interferences. It has to be noted that the transmission of "0" has to be preferred to "1" as it does not create any channel perturbation and it is also possible to detect it at a greater distance. Two ameliorations of TS-OOK are proposed. First, using a low-weight channel coding allows to reduce the influence of interference between concurrent transmission leading to better aggregated bandwidth [16]. Second, Rate Division TS-OOK is proposed in [19] where the time interval between pulses can vary between transmitters. This is done to avoid series of collisions between two nodes. Indeed, in TS-OOK, as the interval was a pre-determined fixed value, if two nodes are emitting at the same time all their transmissions would be in collision. Together with RD TS-OOk, a medium access control (MAC) is proposed. PHysical Layer MAC Protocol for Electromagnetic nanonetworks (PHLAME) main proposition is a handshaking protocol which allows multiple receptions, defines the interval length between two pulses and chooses the best channel coding scheme to increase transmission reliability. The handshaking protocol consists of two phases: a transmission request, starting the handshake and a transmission confirmation, confirming the handshake. Finally, in [25], a new MAC protocol is proposed aiming to optimize the energy consumption in order to match the potential energy harvested.

2.2 Nano-Sim

Many network simulators allow using wireless networks, but the two most used in the research community are NS3 [13] and OMNeT++ [24]. Both of them offer modularity and support for mobility as well as wireless transmission. NS3 is an open source network simulation that is mainly used for education and research in computer communication networks. Simulations are programmed only in C++ while the previous version, NS2, used OTCL and C++ which can lead to larger abstraction that are harder to validate. NS3 have various capabilities such as usage of real IP addresses, multiple interfaces per node, it supports BSD-like sockets, and packets can contain real information. NS3 is supported by an active community that works on many topics (groups), and researchers can validate their contribution by comparing the existing ones. Furthermore, only NS3 has a plugin for nano-wireless simulation. Preliminary works have, indeed, been done in Nano-Sim [21] which is a plugin of NS3.

Nano-Sim allows to evaluate Wireless NanoSensor Networks (WNSN) performances. It has been used to test health care applications and it comprises three types of WNSN devices:

- Nanonode: It is the smallest device and it can be seen as a sensor collecting information such as chemical reaction or multimedia content (sound, image and video). This device has limited capabilities in computational, storage and communication range.
- Nanorouter: This device has larger capabilities than a nanonode, it can receive and forward information to the nanointerface or to other nanorouter.
- Nanointerface: This device can be considered as the sink which process information from sensors. This device can also be used as a gateway to another network e.g: WiFi, LTE, etc.

The network architecture consists of four layers:

- Application Layer (Message Processing Unit class). This layer has the functionality to generate packets using Constant Bit Rate (CBR) and to receive packets from the lower layer.
- Network Layer. This layer has the functionality of passing (receiving and forwarding) packets between nanosensors and nanorouters to nanointerfaces. A header

is added to the packets coming from the application layer. It has five fields: source Id, destination Id, time to live (TTL), packet Id, and tag (packet from sensor or router). There are two protocols for this layer:

  - Flooding Routing protocol: the device sends packets to all devices within its transmission range.
  - Random Routing protocol: the device select randomly the next hop from its neighbors, which can provide service as point-to-point communications.

  In both protocols, to prevent duplicate packets the device keeps a list of 20 received packet Id.

- Medium Access Control (MAC). It provides synchronization among nodes using two strategies. The Transparent MAC method simply transmits packets from the network layer to the physical layer without any control, whereas the Backoff MAC method stores received packet into a queue. It sends the packets when at least one node is in its transmission range. If no other node is in its range, the device applies a random delay prior to starting a handshake procedure.
- Physical Layer. A nanonetwork operates in Terahertz spectrum using TS-OOK modulation [4] presented in section 2.1.

2.3 Video streaming

Video streaming means that video is seen on the receiver well before the video ends being transmitted, during its transmission. Several kinds of video streaming exist, such as video on demand (VoD), videoconferencing, videosurveillance and broadcasting television. Each of them has its characteristics. For example, VoD needs few lost packets, and all data is already available and stored on a server. Videoconferencing needs a very small delay and jitter, and data is sent as soon as it is generated. Videosurveillance needs small delay, so that intruders do not have the time to alter or remove sensible data. In broadcasting television, data is available a few seconds before transmission and has numerous receivers.

Therefore, video streaming has a real-time specificity. Data needs to arrive in time. Timeliness becomes as important as a loss. Indeed, if a packet arrives at receiver *after* its playing time, it is useless, like a packet loss. Classical issues in IP networks interfering with video streaming are lost packets, delay and jitter. A reason for these issues is that a classical video is inelastic, i.e. data sent does not adapt to network conditions. This means that if the video bitrate is higher than the bandwidth, video will regularly freeze on receiver; if the bitrate is smaller that the bandwidth, network is underutilised. A solution is to make video data elastic through *video adaptation*, for example changing bitrate encoding at sender during streaming in order to always meet network bandwidth. We have in the past assessed video quality [20] and proposed solutions for video adaptation [22] and analysed current solutions [12]. However, we have not worked until now on video transmission in nanonetworks. And we have not found any research article on this topic.

2.4 Quality-of-Experience Monitor

Quality of Experience (QoE) Monitor is an NS3 module which allows to read a video, transmit it using NS3 and reconstruct a valid video file from the received data. It also computes PSNR and SSIM metrics based on the differences between the original video at the transmitter side and the reconstructed video at the receiver side.

At the transmitter side, the video source uses the RTP protocol to fragment the original video into packets. Header information like packet ID, payload size, and timestamps are added. At the opposite side, the video receiver extracts the header from each packet and creates the reconstructed video (video reconstruction). The quality measurement is influenced by the number of dropped packets, the delay and the jitter. In QoE Monitor, the video application is applied to a point-to-point channel and packet loss is determined by the packet loss probability. Dropped packets will cause less received data than transmitted data, which does not allow comparing the video as the reconstructed video will have different frames number compared to the original video. In order to have the same amount of data and yield a valid video data, the receiver replaces all lost packets with dummy data [23].

3. SIMULATION SETUP

Given that experiments are impossible to be done in practice and that there is no simulator of video data transmission on nanonetworks, we decided to use the widely used NS3 simulator and two external modules: Nano-Sim and QoE monitor. Nano-Sim[1] was written at Technical University of Bari in Italy and simulates very roughly a nanonetwork. QoE monitor[2] was written at University of Modena and Reggio Emilia in Italy and features an H264-encoded video reader, a valid video writer where lost bytes are replaced with null bytes, and PSNR and SSIM metric computation.

The two modules did not work out of the box. We used an NS3 version (3.16) which worked with QoE monitor. A first modification was to make QoE monitor work with recent version of libav (a fork of ffmpeg), which is known to change often its API. A second and most difficult challenge was to make Nano-Sim and QoE monitor work together. In both modules, packet sending is done deep inside the module. Our solution was to hack QoE code to replace QoE packet sending with calls to Nano-Sim packet sending. The source code solving these issues is freely available on Internet[3].

Unfortunately, we met limitations, simplifications and bugs in the two modules unsolved for the moment, for example:

- bug: Nano-Sim does reordering of packets whereas it should not. For example, in a simple network with two nodes (source and destination), sometimes a packet B arrives before a packet A which was sent before B.
- limitation: QoE monitor receiver discards a fragment if the previous fragment has not been received, otherwise said packet reordering leads to packet loss. As such, all packets arriving in disorder are replaced by null data in

[1]Downloaded from `http://telematics.poliba.it/index.php/en/nano-sim`
[2]Downloaded from `http://sourceforge.net/projects/ns3qoemonitor`
[3]`http://eugen.dedu.free.fr`

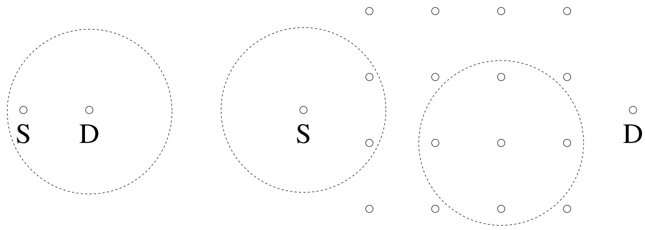

Figure 1: The two nanonetwork topologies used in simulation: on the left side the 2-node topology, on the right side the 18-node topology.

the received data. Real video clients reorder received packets instead. The end result is that the quality of received video in QoE monitor is less than in reality.

- simplification: Nano-Sim has a very simplistic propagation model (all or nothing), where packets are received if they are inside a circle of some radius from the sender, or lost otherwise.

For all these reasons, we consider our work as a rough but first study on video transmission over nanonetworks.

We used two network topologies for the tests, shown in figure 1. The first has two nodes, and is used to check the simulator with the two modules (QoE monitor and Nano-Sim). The second has one source, one destination and 16 relays, and is used to discover how communication is done in a multi-hop network. All the nodes are motionless. The distance between two consecutive nodes is 1 cm. The communication range for all nodes is set to 1.2 cm, and was chosen so that the network exhibit a connectivity of 4 neighbours, and that there are several hops (more precisely 5 hops) between the sender and the destination, and contention in the network during the communication. The molecular communication is used, with flooding routing protocol and TS-OOK modulation. The pulse duration is 100 fs and the pulse interval is 10000 fs, i.e. 100 times greater than pulse duration. The transmitting power is 1000 fW.

There is one flow in the network. The video file used as input is the classical “news” sequence in CIF resolution. The file starts to be sent at second 2. The simulation ends when the file streaming finished. We executed ten times each of the two topologies, and present the results in the next section.

4. SIMULATION RESULTS

The PSNR metric between the received video and the sent video for 2-nodes network is presented in figure 2. It can be seen that all the executions give similar results. Also, the PSNR has a relatively low value (20 to 35 dB) and is quite regular, knowing that 20 to 25 dB are considered to be acceptable values for wireless transmission quality loss. No packet is lost on the network; instead the reordering done by Nano-Sim, as presented in previous section, makes QoE monitor drop packets at receiver. The abrupt changes in PSNR plot, appearing at frames 45, 80 and 130, correspond to abrupt scene changes in video file. The PSNR for 18-nodes network, given in figure 3, is similar to the one for 2-nodes and exhibits the same properties.

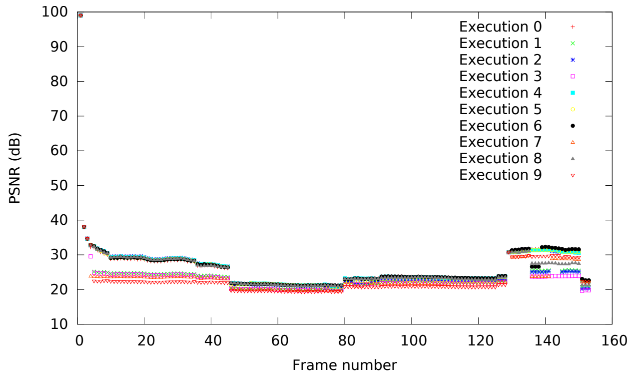

Figure 2: The PSNR for 2-nodes network.

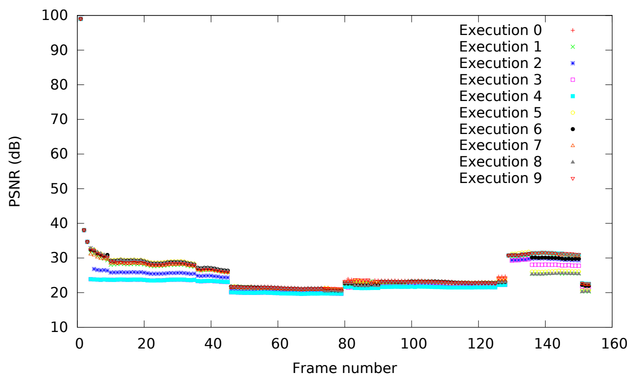

Figure 3: The PSNR for 18-nodes network.

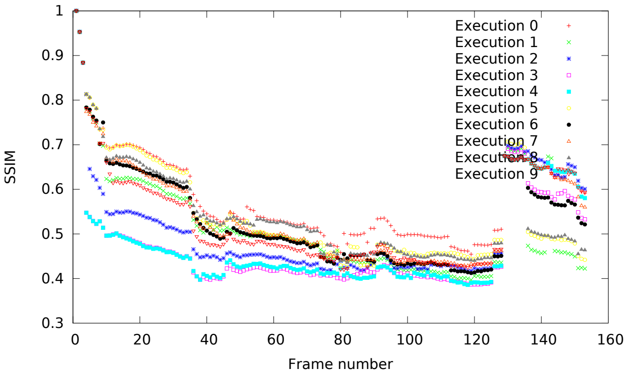

Figure 4: The SSIM for 18-nodes network.

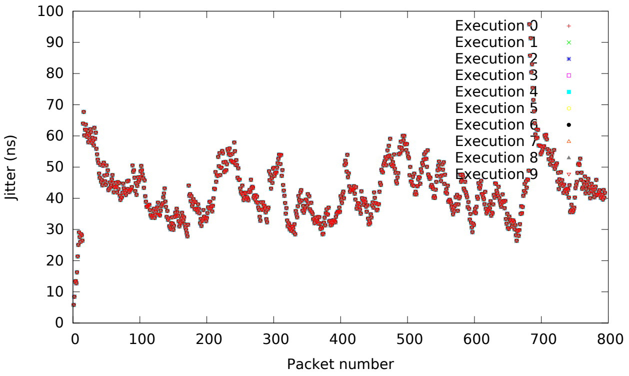

Figure 5: The jitter for 2-nodes and 18-nodes networks.

The SSIM metric for 18-nodes network is presented in figure 4. All the executions give similar values. SSIM curve varies much more than PSNR curve. As for PSNR, SSIM curve varies more at abrupt scene changes, but it is less visible, except for frame 130. The SSIM curve for 2-nodes network is similar to 18-nodes network.

For video transmission, another important parameter is how the packet delay change, because it fixes the receiver buffer size. The jitter (the difference between packet delays) is presented in figure 5. It shows that the jitter varies generally between 30 ns and 70 ns. These values are 3 orders of magnitude lower than what is currently found on Internet, which are of order of tens of ms. As a consequence, the buffers at receiver side could potentially be very smaller than the ones on Internet. However, more importantly, the figure shows that the jitter is identical for all executions, either 2-nodes or 18-nodes. This is an unrealistic result, since in reality the delay and the jitter do depend on the number of hops between sender and receiver (1 hop in 2-nodes, and 5 hops in 18-nodes network). This result shows the limits of Nano-Sim module for video transmission.

5. CONCLUSIONS AND FUTURE WORK

This article presented a study on video transmission over nanowireless networks. We tried to do experiments, but no physical device exists for that. The only possibility to study it is through simulation, using the NS3 well-known network simulator and the QoE monitor and Nano-Sim external modules. PSNR and SSIM quality metrics of the received video, together with jitter graphs have been presented using a 2-nodes and a multi-hop 18-nodes network.

This study is the first to tackle video transmission over nanonetworks. It showed the limitation of the current tools and their models. For example, the jitter results of Nano-Sim and the losses at receiver side in case of unordered packets are not realistic.

The research in this field needs better models and tools. We have started to create a simulator better suited to nanowireless networks and more appropriate to resource-hungry applications like video transmission. Such a tool should take into account channel contention, transmission delays, a more realistic packet loss pattern, allow to read and write video files even at high bitrates, and, last but not least, give reliable results.

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