# ATOM: Adaptive Transport over Multipaths in Wireless Mesh Networks*

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**Abstract.** In this paper we propose the ATOM (Adaptive Transport over Multipaths) architecture to enable real-time communications in Wireless Mesh Networks (WMNs). WMNs provide robust communication facilities which are even available when certain other systems fail. On the other hand, real-time applications (e.g., IP telephony, video conferencing) in WMNs suffer from transmission errors, high delays, etc. caused by the unreliable wireless medium. ATOM reduces these effects by using path diversity and multi-stream coding. At the session establishment, ATOM decides on the used parameter set (encodings, paths etc.) considering current network conditions and collected historic data. Then, after the session establishment, the effect of this decision is continously monitored. If necessary, the decision is adapted.

## 1 Motivation

Wireless Mesh Networks (WMNs) emerge as an important technology for increased wireless network coverage [1] and are becoming more and more popular (MIT Roofnet [2], deployments in cities [3] etc.). Wireless mesh nodes are interconnected by wireless links and therefore WMNs do without a wired backbone. A mesh network is automatically established over the wireless links among the mesh nodes. This multi-hop wireless ad-hoc network is dynamically adapted by its self-organization capability. As all communication inside a WMN is using wireless links, there is no need for a wired backbone like in conventional wireless access networks. This makes the deployment of WMNs relatively easy and cost-efficient.

WMNs provide a robust and redundant communication infrastructure even in situations where existing systems, e.g. GSM (Global System for Mobile Communications), might be overloaded or fail. WMNs are robust against partial failures. Unlike the GSM network, where the failure of one base station disconnects a whole region, WMNs can tolerate node and link failures due to redundancy and self-organization in the network. Therefore, WMNs provide increased network resilience. This makes them an interesting candidate for real-time emergency communications, e.g. IP telephony or video conferencing.

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Unfortunately, the performance of real-time communication suffers from the quality variations of the wireless links in WMNs. The quality of real-time communications is degenerated. The noisy communication channel can cause bit errors in the data transmission. This requires either additional redundancy or retransmissions and therefore reduces the bandwidth. Moreover, fluctuations in the received signal strength due to interference or other changes in the environment can cause link failures. High delays or packet loss rates for the transmission are the consequence. The end user then gets bad quality in his received transmission, e.g., high rate of artefacts, stumbles, or even interruptions. This makes the deployment of real-time applications a challenging task.

Path diversity and multi-stream coding offer support for real-time applications in WMNs. Usually, multiple paths in the network are not affected by the same errors, delays, jitter and loss rates at the same time. Their error characteristics are mostly uncorrelated. Therefore a transmission over multiple paths (path diversity) can compensate the effects of the wireless medium by adding redundancy to the transmission. Instead of simply sending the stream multiple times, advanced multi-stream coding schemes such as layered (LC) or multi-description coding (MDC) can be used [4–6]. Layered coding requires the error free reception of at least the base layer stream to reconstruct the input stream. Whereas in multi-description coding, any combination of received streams can be used for reconstruction. The appropiate selection of encoding and the number of paths depends on the situation [7]. Therefore, the coding selection, the number of used paths, and the mapping of the streams to the individual paths have to be dynamically adapted according to current network conditions.

We propose a new architecture for adaptive transport over multipaths (ATOM) to solve this optimisation problem. ATOM enables real-time communications in WMNs by using path diversity and multi-stream coding. The architecture is described in the next section.

## 2 Architecture of Adaptive Transport over Multipaths (ATOM)

The ATOM architecture enables real-time communication in WMNs. For this purpose, it combines path diversity and multi-stream coding with dynamic adaptation to the current network conditions. Multi-path routing delivers multiple independent paths, the application provides several multi-stream encodings, and the ATOM architecture selects the appropiate set of paths, encoding, and mapping of streams to paths. The decision is supported by network measurements, monitoring, and statistical evaluation. It is adapted if the network conditions have changed.

The ATOM architecture at the end system is shown in Fig. 1. It consists of the following components which are then described in more detail: ATOM controller, ATOM aware application, history and statistical analyzer (HSA), monitoring and measurement system (MMS), multipath routing, path allocator, and end-to-end signalling. Besides these components at the end system, ATOM requires at least the installation of multi-path routing at all mesh nodes. Furthermore, it makes sense to include HSA and MMS in the mesh nodes. The component placement is discussed later.

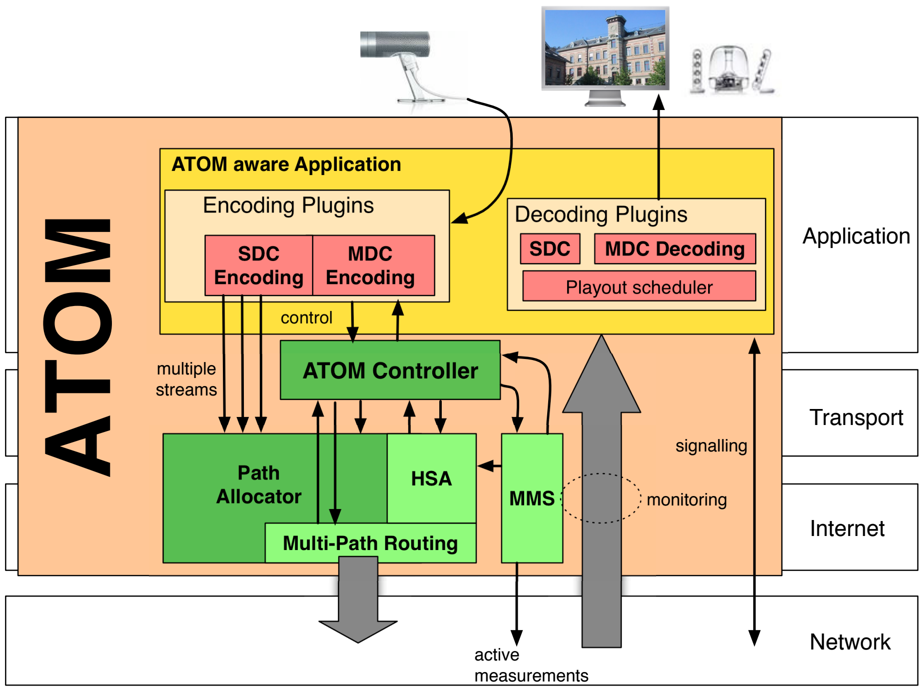


Fig. 1: ATOM end system

The ATOM controller is the central component of the system. It gathers control data and makes the decision about the used communication configuration. The ATOM controller receives data about the available encodings from the application(s), available paths from the multi-path routing, the robustness of the path or individual links from the HSA, and current network conditions from the MMS. Considering this data set, it optimises the parameters for the transmission. This includes the paths to be used, the encoding algorithm (multi-description or layered coding), the number of streams to be encoded, and the mapping of the streams to the paths. If necessary, the ATOM controller triggers the discovery of new paths at the multi-path routing. According to the feedback from the MMS or the application the controller reevaluates the current situation and adapts the transmission parameters accordingly.

The ATOM aware application has to implement the ATOM application programming interface (API) in order to use the ATOM framework. The ATOM API permits the communication with the ATOM controller to exchange the available configuration options and to get the configuration parameters back. The ATOM aware application informs the controller about available codecs and coding options at the initialisation of the transmission. It then receives the configuration set (encoding, number of streams) from the controller. During an ongoing communication, the application (or user) can give feedback to the ATOM controller in order to revise its decision and to release new parameter settings for this transmission.

ATOM introduces a history and statistical analyser (HSA) to further support the decision process of the ATOM controller. HSA analyses the received data from MMS and provides robustness information about individual paths, regularities and periodicities to the ATOM controller. The received measurement data from the MMS is analysed and stored as a compact meta data description. The description contains information about the stability (fluctuations in availability, bandwidth, and delay) of the paths and the links during the last week, days, hours, and minutes. It further lists remarkable regularities and periodicities in bandwith, delays, and outages.

The monitoring and measurement system (MMS) observes the network conditions and the quality of ongoing transmissions. This is done by active (network probes) and/or passive measurements. The measurement results are then sent to the ATOM controller as description of the current network state and to the HSA for statistical evaluation. In addition, MMS monitors the current transmissions and provides quality feedback to the remote ATOM controller at the destination.

The required multiple paths from source to destination are delivered by a multi-path routing protocol to the ATOM controller. There are several multi-path routing protocols existing, e.g., AODVM [8], SMR [9], and MP-DSR [10]. We therefore propose to adapt an existing multi-path routing protocol to the ATOM architecture. The routing protocol has to deliver paths that are as independent as possible with certain quality of service (QoS) requirements, e.g., delay below 150ms. The independence of the paths is important in order to take profit of the path diversity and not to be affected by single link and node failures. Moreover, the routing protocol has to deliver the paths marked with a degree of independence (shared links, shared nodes) and QoS parameters to the ATOM controller for the decision making process. We currently favor source routing protocols like SMR and MP-DSR as they deliver the full path in the route discovery process. This eases the path allocation according to QoS parameters. In addition, each packet includes the whole path, which simplies the monitoring. However, we will evaluate several candidate protocols for routing.

Multi-channel communication can significantly increase the throughput of WMNs. The routing protocol has to consider the presence of multiple channels and radios in its routing decision in order to fully take advantage of the multi-channel communication. This requires more advanced routing metrics than hop count. The hop count metric is based on the wrong assumption that a link either works or not. Packet loss, bandwidth, varying delays, and (self-)interference are not considered. Different enhanced routing metrics are existing, e.g., MIC (Metric of Interference and Channel-Switching) [11], and iAWARE [12]. iAWARE seems to be the most appropriate metric to start with as it incorporates packet loss, bandwidth, intra-flow interference, and inter-flow interference considering signal strength and traffic amount of the interfering flows. We will therefore evaluate and adapt iAWARE as routing metric for our multi-path routing.

The path allocator is reponsible for the allocation of the individual streams from the application to the paths according to the settings received from the ATOM controller. It also delivers the received streams to correct application at the destination.

End-to-end signalling is required for adjusting the parameters at both communication peers. The ATOM aware applications have to signal their encoding options to the ATOM controller and the ATOM controller has to inform the applications and its remote ATOM peer about the used parameter set. A possible signalling protocol for this purpose is SIP (Session Initiation Protocol).

The ATOM components can be placed at different locations in the WMN. Either all components are included in the end system (see Fig. 1) or the core components are only situated in the WMN at the first and last hop router. The placement in the end system requires modifications at each individual client. Besides the ATOM aware application, the ATOM core components have to be installed on the client. This requires modifications in operating system components and all ATOM components have to be provided for the different operating systems of the client devices. Another possibility is to include the ATOM components only in the mesh nodes. In this case, only the ATOM aware application has to be installed on the client devices. There is no need for porting the ATOM core components to the different client operating systems. They have only to be available for the mesh nodes. The ATOM aware application then communicates with the ATOM controller over TCP/IP. Compared to the approach with ATOM at the end system, the mesh only ATOM system may depend on the transmission quality of the link between client and ATOM mesh node. In addition to these approaches, the ATOM architecture supports a combination of the both approaches (some clients with ATOM core, some without) or even legacy applications by interception of the traffic at the border mesh nodes.

## 3 Summary and Future Work

Wireless Mesh Networks provide a reliable and robust communication infrastructure even in situations where other systems may fail. But, it is a challenging task to use them as communication backbone for real-time emergency communications such as IP telephony and video conferencing. The main problem are transmission errors, link errors, packet loss, high delays, and high delay variations caused the unreliable and erroneous wireless medium. This makes the deployment of real-time applications difficult as the user perceived audio/video quality is degenerated (stumbles, artefacts, high delays, or connection losses). Our proposed ATOM (Adaptive Transport over Multipath) architecture provides a comprehensive solution for the support of real-time communication in WMNs. It reduces the effects of the unreliable and erroneous wireless medium by using path diversity, multi-stream coding, and dynamic adaptation.

The presented ATOM architecture is work in progress and we are currently specifying its details. We have also started to implement and test parts of the architecture in a network simulator. Further ongoing activities are the elaboration of decision making process of the ATOM controller and the statistical analysis in HSA. We also plan to implement and evaluate the ATOM architecture on our Linux based wireless mesh network. In order to perform experiments in the WMN at our institute, we have developed a remote management and software distribution solution [13].

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