# Analysis of Cross-Layer Interactions for VoIP Services over Ad-Hoc Networks

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**Abstract.** This paper examines the cross-layer interactions of different protocols, for wireless ad-hoc networks in the presence of VoIP traffic. VoIP traffic in mobile wireless Ad-Hoc networks is severely affected by interactions between different layers. The reliability and the strict congestion control offered by TCP is often times unnecessary. At the same time the prioritization scheme of 802.11e favours delay-sensitive traffic, hence it enhances the VoIP performance. We concentrate our work in the Transport and the Routing layer, where different protocols have different impact on the way the VoIP traffic performs. Using a simulation environment, these interactions have been studied among the following protocols on the transport layer (i.e. TCP, DCCP, SCTP), the routing layer (i.e DSDV, AODV, DSR) and the MAC layer where the 802.11e is utilized. The impact of these parameters on voice quality in terms of throughput, packet loss, delay and jitter are evaluated.

**Keywords:** cross layer interactions, voip traffic, routing protocols, DCCP, TCP friendly, 802.11e.

## 1 Introduction

Mobile Ad-Hoc networks are built by moving nodes that may establish communication with each other in a random manner. Data traffic faces many challenges over this type of networks, due to the wireless medium and the lack of a predefined infrastructure [11]. Congestion ceases to be virtually the only reason for packet loss and other factors such as re-routing and signal loss also cause packet drops which add to the overall losses.

In addition, real-time traffic such as Voice over IP (VoIP) has some specific timing constraints, mainly related to the delay and the delay variation (jitter) that sometimes are not met by the protocols used in wired networks. TCP in particular offers tight congestion control and unnecessary reliability that eventually hurts the VoIP traffic and degrades the performance. Similarly, on the Medium Access Control (MAC) layer the contention for the medium also affects the performance as it may increase the delay which primarily affects real-time

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traffic. Routing protocols can have different interactions based on the level of mobility.

Depending on the requirements of different applications, several protocols are currently used at the Transport, the Routing and the MAC layers.

The Datagram Congestion Control Protocol (DCCP) for example was proposed as a transport protocol, designed to better support streaming data by providing the ability to have more options for congestion control [8].

802.11e introduces a prioritization scheme to reduce the medium access time. It creates virtual queues, configured by the parameters Transmit Opportunity (TXOP), Arbitration Interframe Space (AIFS) and Contention Window (CW). They simulate categories with different access priorities, depending on the type of traffic, such as VoIP (highest priority) or Background Traffic (lowest priority). By reducing the medium access time of a queue, 802.11e increases the priority of its traffic.

The Binomial TCP-Friendly scheme was proposed as a configurable Congestion Control scheme that uses the parameters $k$, $l$, $\alpha$ and $\beta$ to increase or decrease the Congestion Window of the node. In particular $k$ and $l$ are the exponents of the current window size and define the TCP-Friendliness, while the constants *alpha* and *beta* further control the increase and decrease rate in order to reduce the oscillations [5]. The Additive Increase-Multiplicative Decrease (AIMD) congestion control scheme, employed by TCP, can be over aggressive when it consumes the available bandwidth and also very strict when reducing the window size once congestion is detected. However congestion is not the only reason that causes packet loss in a wireless network. Moreover real-time traffic can benefit by a smoother and more adaptable scheme. The Binomial TCP-Friendly retains the TCP-Friendliness and at the same time it controls the increase and decrease rate of the congestion window which may reduce the unnecessary window size oscillations that hurt the real-time traffic in wireless networks.

Configuring some of these protocols can significantly alter their behaviour, depending on the type of the traffic and the condition of the network. The goal of this work is to further examine the interactions between these protocols since better understanding them is the essence for a successful cross-layer design [12]. We locate these interactions, point out the improvement achieved and discuss reasons that lead to these results.

The rest of this paper is organized as follows. Section 2 briefly mentions previous work and Section 3 presents the Simulation setup and the main results for several scenarios where different transport and routing protocols are used over an 802.11e-based wireless network. Section 4 discusses the main results and extracts some general conclusions based on the characteristics of each protocol. Section 5 concludes the paper and briefly presents some ideas for the future work.

## 2 Previous Work

Many cross-Layer schemes have been proposed for wireless networks. The classic OSI model with the independent layers that do not interact with each other can sometimes be inadequate for the case of the wireless networks [11], where several new challenges emerge, such as the mobility and the reduced signal strength. When real-time traffic is conveyed over mobile wireless networks, it becomes more essential to develop a cooperation between protocols in different layers to improve the performance and meet the stringent requirements. In [1] the authors propose the FeW scheme that controls the increase rate of the TCP Congestion Window. Thus they replace the AIMD scheme and prevent the nodes from overloading a wireless network which usually has a small delay-bandwidth product. In [2] the authors examine how a Binomial TCP-Friendly scheme can co-exist with the 802.11e protocol over a Wireless Network and improve its performance by configuring appropriately the parameters.

In [5] the authors propose a new TCP-Friendly congestion control algorithm, called Binomial which controls the increase and decrease rate of the TCP Congestion window. The goal is to reduce the throughput variations caused by the aggressiveness of AIMD which can be harmful for certain streaming applications. At the same time, the condition $k + l = 1$ and $l \leq 1$ guarantees the TCP-Friendliness for certain *alpha* and *beta*. In [6] the authors utilize this scheme to improve the performance of real-time similar data over wireless networks. In particular, they propose the 802.11e that provides different prioritization for different data types, in parallel with the the TCP-Friendly Binomial scheme for the Transport Layer.

Real-time applications such as VoIP depend primarily on a low delay variation (jitter) to retain a high quality for the reproduced audio, without the need for the reliability offered by TCP. DCCP is a transport protocol that provides congestion control but at the same time is unreliable [7], similar to UDP. In [8] the author creates an DCCP implementation for the NS-2, which is used to perform our DCCP simulation scenarios. In [4] the authors perform a modelling analysis for the VoIP traffic and they suggest that a generalized Pareto distribution is most appropriate for modelling the call holding time. We follow this approach in our simulation scenarios.

## 3 Simulation Results

This section describes the simulation setup, the software packages used, the protocols that are examined and the metrics to evaluate the results. We present the simulation scenarios starting with no background traffic which is later increased to medium and high. Different configuration parameter sets for the TCP-Friendly Binomial scheme are also examined as well as the SCTP protocol in a simulation scenario with high background traffic.

### 3.1 Simulation Setup

The NS2 simulator [9],[14] is utilized to perform the simulation scenarios. A number of wireless nodes with certain mobility, initially move around a flatgrid and then stop at some predefined positions. Their speed is 4.5 m/s. We have integrated the DCCP patch [8] for the NS-2. However using DCCP over DSDV resulted in some error messages from the NS-2 simulator, regarding certain packets and hence some results have not been included. These errors are probably related to the DCCP implementation and one of the Options present in the DCCP header called Ack Vector and its size. We utilize the 802.11e EDCA implementation from the Telecommunication Networks Group of the Technische Universitt Berlin (TKN) [3], which is integrated to the NS-2. Since we examine the interaction on VoIP traffic we give the VoIP stream the highest priority on the MAC layer.

We use different routing protocols for our experiments, namely the Destination-Sequenced Distance Vector (DSDV), the Ad-Hoc On-Demand Distance Vector (AODV) and the Dynamic Source Routing (DSR). Similarly we examine different transport protocols, namely the DCCP, the Binomial TCP-Friendly and the legacy TCP. We also present some initial results from using the SCTP protocol.

Further we use the Pareto distribution to simulate the traffic produced by a VoIP source. Finally, we inject CBR Background traffic to the network to further increase the load and the packet loss due to congestion.

The metrics used to evaluate the performance are the Average Throughput measured in kbps, the Jitter and the Delay measured in msecs and the Packet Loss measured in lost packets percentage over total number of packets. We use Marco Fiore's measurement scripts [13]. The results are presented in Figures 17-20 in the Arithmetic Results subsection. We also present several graphs for the Instant Throughput and the Instant Jitter over simulation time, to show the behaviour of these protocols when different traffic load exists on the network.

The first scenario compares the DCCP with the TCP-Friendly Binomial scheme when AODV, DSDV and DSR are used successively as the routing protocols. No background traffic exists in the network (low traffic case). Next we inject some CBR background traffic (medium traffic case) in the wireless network and we compare the DCCP and the TCP-Friendly again, using the AODV and DSDV routing protocols. This scenario is repeated with a different parameter set for the TCP-Friendly Binomial scheme. The setup of the next experiment includes heavier background traffic, where the CBR connections produce higher number of packets which increases the packet loss in the whole network. Again the DCCP and the TCP-Friendly Binomial are examined over the AODV and DSDV routing protocols. In the last simulation scenario, we examine the case of the SCTP transport protocol over both AODV and DSDV with heavier background traffic.

### 3.2 DCCP and Binomial TCP Friendly without Background Traffic

In our first scenario we examine the case of 3 TCP flows with no background traffic. This lightweight scenario has virtually no packet losses. 802.11e is used as the MAC layer protocol. We utilize three different routing protocols, namely the AODV, the DSDV and the DSR. In the transport layer we examine the DCCP

(TCP-Friendly Rate Control (TFRC) case), the Binomial TCP-Friendly (with a certain set of values for the $\alpha$ and $\beta$ parameters) and the plain TCP.

The following Figure 1 shows the Instant Throughput and Figure 2 the Instant Jitter over Simulation Time, when AODV is the routing protocol.

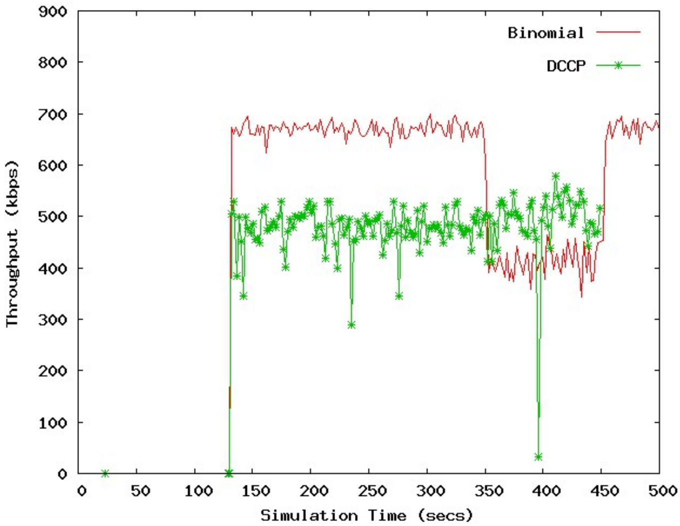


**Fig. 1.** Throughput variation for the DCCP and the Binomial TCP Friendly case, over AODV with no background traffic

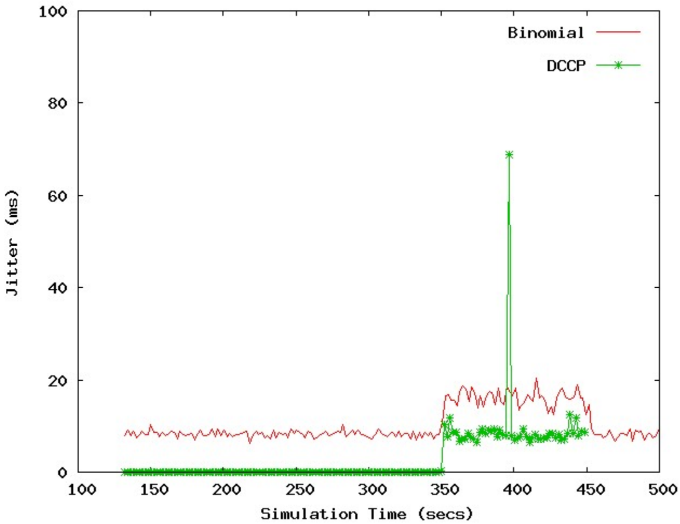


**Fig. 2.** Jitter variation for the DCCP and the Binomial TCP Friendly case, over AODV with no background traffic

The performance results are summarized in Figures 17-20. DCCP achieves a more stable behaviour and most times a lower jitter. When another TCP flow initiates at 350 secs and terminates at 450 secs, the performance deteriorates. However DCCP shows a more stable behaviour than the Binomial TCP-Friendly, regarding the Instant Throughput Variation.

Next we examine the same scenario where the routing protocol is now the DSDV. Note that as mentioned earlier, the DCCP over the DSDV case resulted in some error messages. However for the sake of completeness we present the results. The Instant Throughput is presented in Figure 3 :

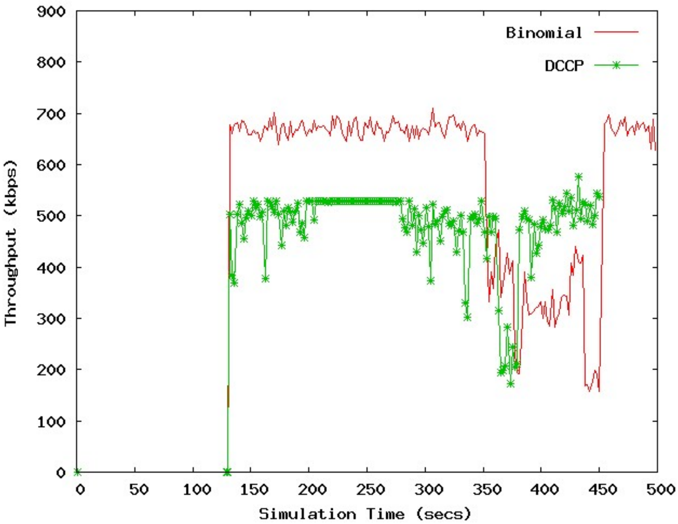


**Fig. 3.** Throughput variation for the DCCP and the Binomial TCP Friendly case, over DSDV with no background traffic

Next we examine the same scenario but now the routing protocol is changed to DSR. The Instant Throughput is presented in Figure 4 and the Instant Jitter in Figure 5:

Again the DSR achieves a more stable behaviour during the simulation time where other traffic is inserted to the network. DCCP appears to be more efficient in the case of reduced Jitter, which is an essential factor for the VoIP traffic.

### 3.3 DCCP and Binomial TCP Friendly over a Medium Loaded Network with CBR Background Traffic

In this scenario we introduce CBR background traffic to the wireless network with 7 nodes. Initially we compare the behaviour of DCCP and Binomial TCP-Friendly protocols over AODV. The Instant Throughput is shown in Figure 6 and the INstant Jitter in Figure 7:

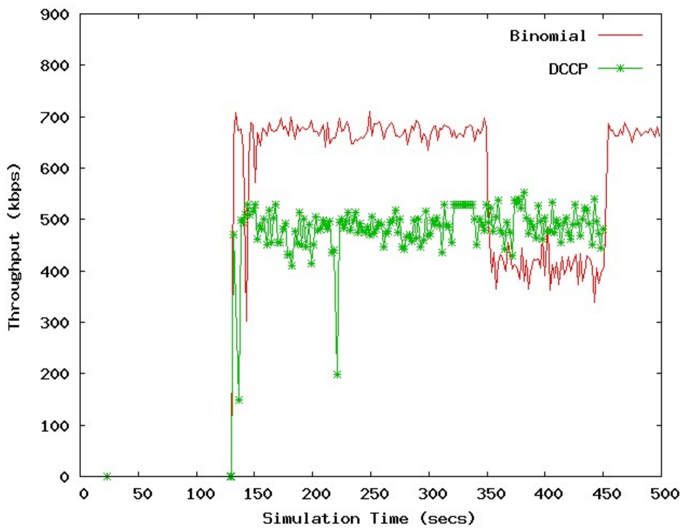


**Fig. 4.** Throughput variation for the DCCP and the Binomial TCP Friendly case, over DSR with no background traffic

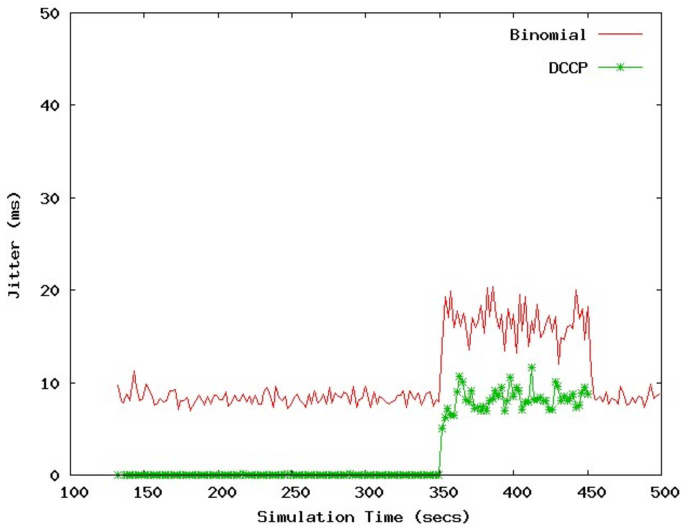


**Fig. 5.** Jitter variation for the DCCP and the Binomial TCP Friendly case, over DSR with no background traffic

We note that DCCP continues to behave more stable even in the case where CBR background traffic is injected to the network.

Next we examine the same scenario where now the routing protocol is changed to DSDV. Again we note that there were some NS-2 error messages regarding

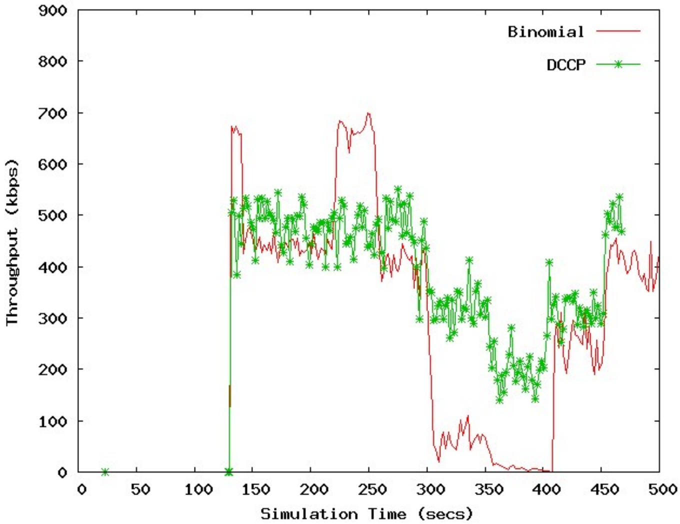


**Fig. 6.** Throughput variation for the DCCP and the Binomial TCP Friendly case, over AODV with medium background traffic

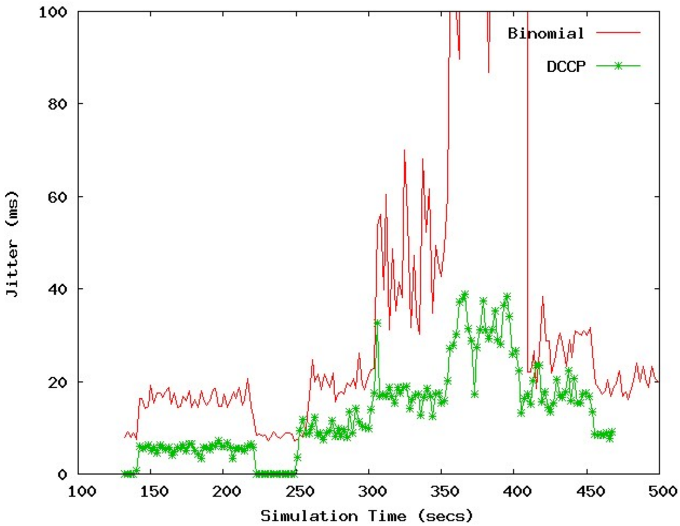


**Fig. 7.** Jitter variation for the DCCP and the Binomial TCP Friendly case, over AODV with medium background traffic

some packets, when DCCP was used over DSDV. The Instant Throughput is presented in Figure 8 :

AODV appears to improve the Packet Loss and the Delay when medium traffic is inserted to the network. It also shows to improve the Packet Loss even when

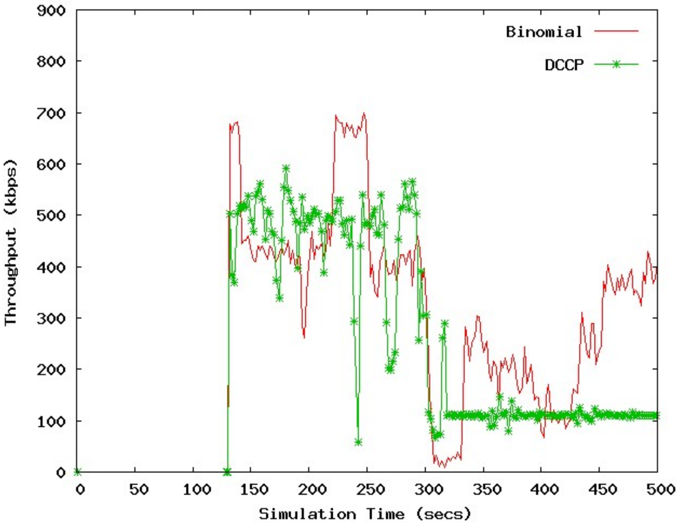


**Fig. 8.** Throughput variation for the DCCP and the Binomial TCP Friendly case, over DSDV with medium background traffic

different transport protocols are used. DCCP appears to be the most efficient protocol in the case of reduced Jitter, which is an essential factor for the VoIP traffic. Similarly it reduces the Packet Loss in the cases of medium and heavier traffic load.

### 3.4 Configuring the Binomial TCP-Friendly Protocol

In the following scenario we compare two different sets for values $alpha$, $beta$, $k$ and $l$ of the Binomial TCP-Friendly protocol under the DSDV routing protocol. These specific parameter sets that we use, have shown to produce better results, through simulations and in [2]. Figure 9 presents the Instant Throughput and Figure 10 the Instant Jitter:

Small differences are obvious between the two value sets.

### 3.5 DCCP and Binomial TCP Friendly under Heavier CBR Background Traffic with Higher Packet Loss

The following scenario introduces heavier background traffic which leads to higher packet loss. We first compare the DCCP and Binomial TCP-Friendly Throughput over AODV. Figure 11 shows the Instant Throughput and Figure 12 the Instant Jitter:

Again the Throughput variations are smaller in the case of DCCP and the Jitter is also lower .

The same scenario is now simulated using DSDV. Again the NS-2 gave us some error messages when DCCP is used over DSDV. The following Figure 13 shows the Instant Throughput and Figure 14 the Instant Jitter:

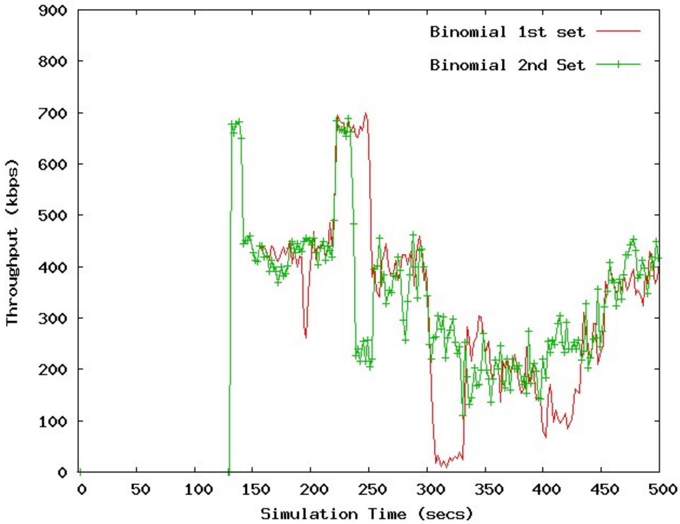


**Fig. 9.** Throughput variation for different parameter sets of the Binomial TCP Friendly case, over DSDV with medium background traffic and different Binomial parameters

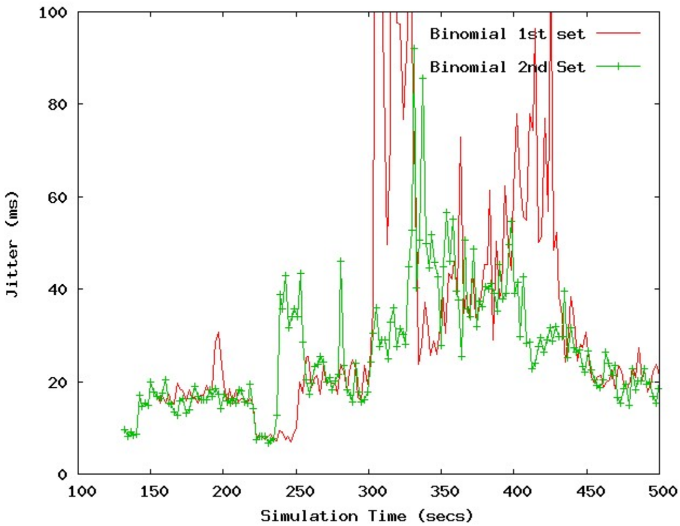


**Fig. 10.** Jitter variation for for different parameter sets of the Binomial TCP Friendly case, over DSDV with medium background traffic and different Binomial parameters

AODV appears to perform better than DSDV in terms of Delay, Jitter and Packet Loss as shown in Figure 17-20. DCCP over AODV achieves the lowest Jitter which is an important factor for the VoIP traffic. It also has the lowest Packet Loss.

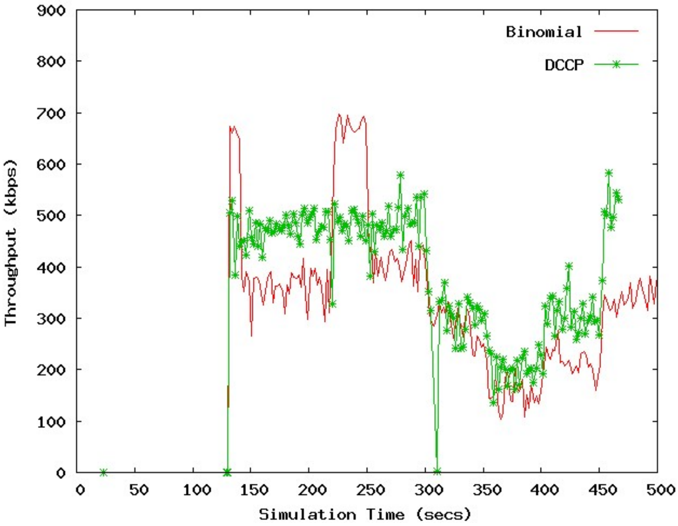


**Fig. 11.** Throughput variation for the DCCP and the Binomial TCP Friendly case, over AODV with heavier background traffic

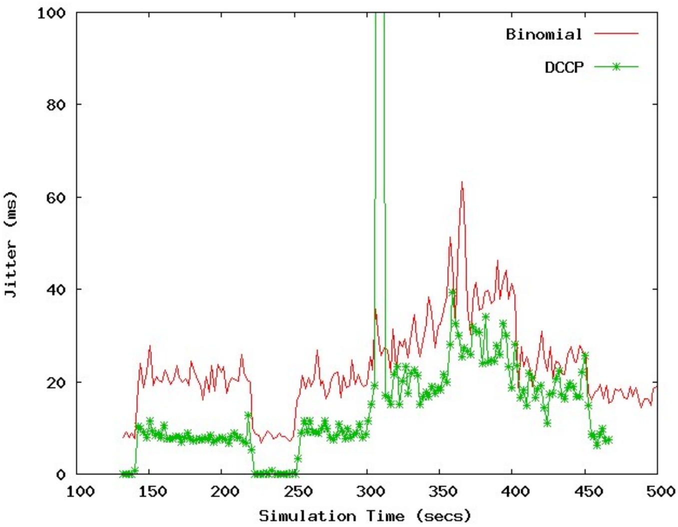


**Fig. 12.** Throughput variation for the DCCP and the Binomial TCP Friendly case, over AODV with heavier background traffic

AODV reduces the number of sent messages and thus the consumption of network capacity [7]. DCCP is a message-oriented protocol with unordered delivery and no reliability [10]. TCP may cause more reactions of the routing protocol [1], while DCCP, by avoiding retransmissions in a continuously changing topology,

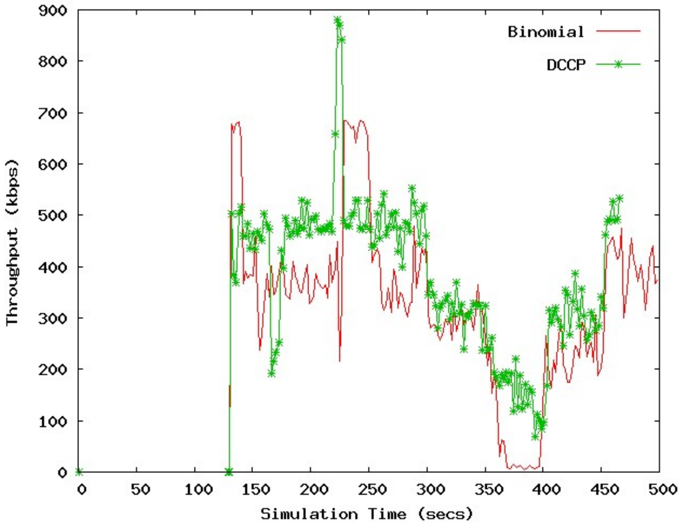


**Fig. 13.** Throughput variation for the DCCP and the Binomial TCP Friendly case, over DSDV with heavier background traffic

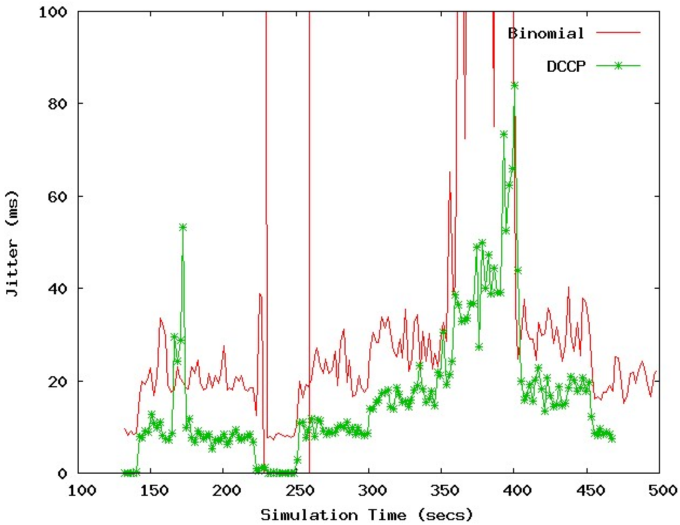


**Fig. 14.** Throughput variation for the DCCP and the Binomial TCP Friendly case, over DSDV with heavier background traffic

prevents AODV from re-establishing a possibly lost route to re-send a lost packet. Hence it may further reduce the messaging overhead. Streaming data such as VoIP over a wireless Ad-Hoc network is probably favored by the combination of these features.

### 3.6 SCTP over AODV and DSDV under Heavier Background Traffic

For the sake of completeness we also present some initial results when using the Stream Control Transmission Protocol (SCTP) as the transport protocol, again under heavier background traffic. Both AODV and DSDV have been used as the routing protocols.

The rest of the simulation setup remains the same. The following Figure 15 shows the Instant Throughput variations when SCTP is used over AODV and DSDV.

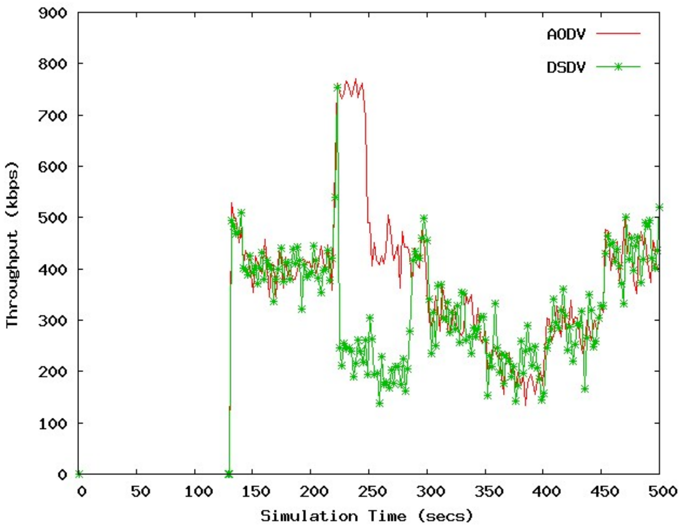


**Fig. 15.** Throughput variation for SCTP over AODV and DSDV with heavier background traffic

Obviously, the AODV reacts more efficiently in the simulation time period from 210 to 280 seconds.

This can also be seen in Figure 16 where the Instant Jitter is presented in both cases of AODV and DSDV.

Again in Figures 17-20 we present the remaining results from using SCTP as the Transport protocol. This scenario case clearly shows that SCTP over AODV achieves higher performance even with heavier network load. The Packet Loss, the Jitter and the Delay are improved compared to the case where DSDV is used. The Average Throughput is also higher. This improved behaviour is presented in Figure 15 where the SCTP Instant Throughput reacts better in the time period from 210 to 280 secs when AODV is used. Similarly in Figure 16, the Instant Jitter is lower in the same time period). Overall SCTP shows in most cases a decreased performance, compare to the other transport protocols. However this is probably due to the fact that it is designed to carry mainly signalling packets

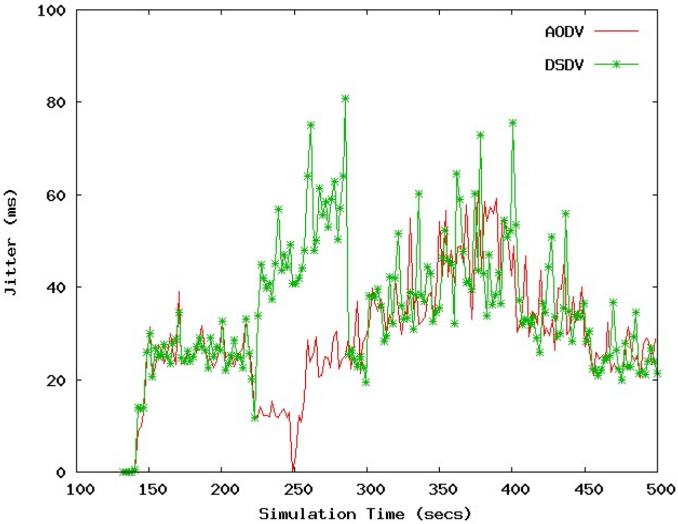


**Fig. 16.** Jitter variation for SCTP over AODV and DSDV with heavier background traffic

and not the bulk traffic of the packetized voice. According to that, SCTP is not an appropriate protocol for carrying VoIP traffic over a wireless network.

### 3.7 Measured Results

This paragraph presents the measured results from all the simulation scenarios. We also include the results for the case of plain TCP which was not analysed before. Again we note that there were some NS-2 error messages, regarding some packets when DCCP was used over DSDV. Figures 17-20 present the Throughput in kbps, the Delay in msecs, the Jitter in msecs and the Packet Loss in %.

| THROUGHPUT (kbps) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | AODV | | | DSDV | | | DSR |
| | LOW | MEDIUM | HIGH | LOW | MEDIUM | HIGH | LOW |
| TCP | 600 | 313 | 361 | 571 | 355 | 325 | |
| BINOMIAL | 600 | 328 | 340 | 575 | 311 | 326 | 596 |
| DCCP | 480 | 388 | 382 | 482 | 370 | 382 | 582 |
| SCTP | 480 | 333 | 382 | 480 | 348 | 320 | |

**Fig. 17.** Throughput in kbps

| DELAY (msecs) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | AODV | | | DSDV | | | DSR |
| | LOW | MEDIUM | HIGH | LOW | MEDIUM | HIGH | LOW |
| TCP | 253 | 353 | 388 | 257 | 356 | 396 | |
| BINOMIAL | 244 | 192 | 319 | 245 | 190 | 193 | 243 |
| DCCP | 118 | 317 | 424 | 118 | 368 | 488 | 87 |
| SCTP | 179 | 474 | 741 | 177 | 672 | 849 | |

**Fig. 18.** Delay in msecs

| JITTER (msecs) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | AODV | | | DSDV | | | DSR |
| | LOW | MEDIUM | HIGH | LOW | MEDIUM | HIGH | LOW |
| TCP | 9.7 | 19 | 21.3 | 10.7 | 21 | 23.8 | |
| BINOMIAL | 9.7 | 18.5 | 19.9 | 10.5 | 22 | 26 | 9.9 |
| DCCP | 2.7 | 10.5 | 11 | 3.1 | 11.4 | 11.7 | 2.7 |
| SCTP | 6.1 | 18.2 | 25.9 | 5.6 | 25.1 | 31.2 | |

**Fig. 19.** Jitter in msecs

| PACKET LOSS (%) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | AODV | | | DSDV | | | DSR |
| | LOW | MEDIUM | HIGH | LOW | MEDIUM | HIGH | LOW |
| TCP | 0.08 | 8.4 | 18.18 | 0.15 | 10.1 | 24.1 | |
| BINOMIAL | 0.07 | 7.83 | 15.88 | 0.12 | 9.53 | 20.9 | 0.1 |
| DCCP | 0.16 | 1.82 | 11.37 | 0.63 | 5.74 | 18.3 | 0.05 |
| SCTP | 0.25 | 6.03 | 14.23 | 0.33 | 6.56 | 18.2 | |

**Fig. 20.** Packet Loss (%)

Note that in all cases, TCP over AODV performed better than over DSDV in terms of throughput, delay, jitter and packet loss. TCP achieves good throughput performance when the background traffic is lower. However the TCP performance deteriorates with heavier background traffic, especially in terms of packet loss and jitter. TCP achieves lower Jitter than SCTP under heavier traffic load. Hence TCP, similarly to SCTP, cannot efficiently be used to convey VoIP traffic.

## 4 Conclusion

This paper examines the impact of different protocols on VoIP services caused also by the interactions between different layers. These interactions show that the VoIP traffic is affected by different routing and transport layer protocols.

We observe that the usage of the DCCP scheme as the Transport layer protocol significantly improves the performance of the VoIP traffic when compared to the Binomial TCP-Friendly and the legacy TCP. Some initial results from the usage of SCTP are also presented. We also present the effect of the different routing protocols to this traffic and how we can further enhance the performance of DCCP by using an appropriate routing protocol, such as the AODV. DCCP over AODV appears to be the most efficient combination for conveying VoIP traffic over Wireless Networks in terms of Jitter, Packet Loss and Average Throughput under different background traffic conditions. When it comes to the Delay, the Binomial TCP-Friendly achieves lower values, which shows a better co-operation with the AODV. For our simulation scenarios, we utilize the 802.11e on the MAC layer, giving higher priority to the VoIP traffic.

Part of our future work, includes a theoretical analysis that explains the observed results. We also plan to examine how we can optimize the performance of these schemes by jointly configuring the appropriate protocol parameters on different layers.

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