Packet jitter measurement in communication networks: a sensitivity analysis

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Abstract— **Communication networks are widespread today. New services are now starting to run on these networks to meet the requests of modern users. To offer good service typically hard constraints have to be satisfied, especially when real-time services are involved. To this aim the reliable estimation of Quality of Service (QoS) parameters as bandwidth, packet jitter, latency, one way delay, to cite a few, is a key issue for communication networks setup, monitoring and tuning.**

Generally, the measurement of QoS parameters is a complex process that involves several troubles. Some of them depend on the measurement network features: (i) the medium employed to convey the data stream (optic fiber, wireless, wired, etc.), (ii) the type and number of network devices involved (network interface cards, switches, routers, etc.), (iii) the type of communication and access protocols, and (iv) the variability of the network background traffic which could strongly influence the measurement result.

Further troubles come from the measurement chain and the measurement method adopted: type of measurement instruments, sampling and observation times, packet size, type of measurement post processing to cite a few. Therefore, they can be thought as sources of measurement uncertainty able to strongly influence the measurement process and the reliability of the results.

With reference to the measurement chain and the measurement method adopted, in this paper a deep sensitivity analysis aimed to identify the main quantities influencing the measurement results and to study their modeling as uncertainty components is performed. The attention has been focused on the packet jitter estimation made on a real test bed: the fiber optic based local area network of the University of Cassino (Italy).

Keywords - Communication networks test and measurement, quality of service (QoS), packet jitter, measurement uncertainty, metrological characterization.

I. INTRODUCTION

During the last years, our lives and working activities are increasingly influenced by communication and computer networks. Many scientific, manufacturing, social and financial applications are now implemented in modern networks. To warrant the expected quality of services to the user, suitable management and monitoring policies have to be adopted to minimize the downtime and inefficiency costs, particularly when performance critical applications, such as real-time services, are involved [1]. In this framework the reliable measurement of Quality of Service (QoS) parameters becomes a fundamental issue to be effectiveness accomplished. Typically, this measurement activity requires the evaluation of several indexes as: throughput, available bandwidth, packet jitter, one way delay, round trip delay, and packet loss [2]-[4]. A reliable evaluation of such quantities is fundamental for network managers to fine-tune, troubleshoot the network and to maintain its efficiency [5]-[7]. More in detail, the analysis of such indexes allows i) optimizing the algorithm of flow control and routing, ii) developing strategies and algorithms for the detection of unwanted traffic and intrusion, and undesired behaviors, iii) evaluating the network capability in supporting new value added services [8],[9].

The estimation of the above-mentioned QoS index is not a trivial task because it generally depends on the interaction of a number of parameters.

Some of them are related to the measurement network, as: the medium employed to convey the data stream (optic fiber, wireless, wired, etc.), the type and number of network devices involved (network interface cards, switches, routers, etc.), the type of communication and access protocols, and the variability of the network background traffic which could strongly influence the measurement result.

Further parameters are related to the measurement chain and method: measurement instruments, observation times, sampling time and packet size, measurement post processing (numerical decimation, evaluation of the mean value, and so on) to cite a few.

More in detail, focusing the attention on this last class of influencing parameters, some considerations can be drawn:

- measurement instruments are classified in two general classes of measurement systems (also known as "protocol analyzers") based on special and general purpose architectures, respectively. The former (protocol analyzer based on special purpose architectures) is the solution typically adopted by instrument manufacturers which make use of dedicated high performance hardware and software to provide the measurement results. It is characterized by pre-configured measurement and analysis routines, wide decoding capability, accurate timing and synchronization, small size, but relatively high costs [10],[11]. The latter solution (protocol analyzer based on general purpose architecture) is typically based on

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standard computers on which a suitable multi-platform software for traffic generation (often open-source and/or free of charge) and analysis is installed [12]-[15]. Then, it is evident that the choice of the measurement system influences the accuracy of the measurement process.

- The observation time indicates the quantity of time adopted in the collection of QoS parameters. High observation times give out a good statistical analysis but, on the other hand, make the measurement process very time and resource consuming.
- The sampling time indicates the measurement rate of QoS parameters. This parameter is often related to the packet dimension since the considered figure of merit is calculated as the mean value on a number of network packets. For a given network traffic, the higher the rate the lower is the number of packets on which the QoS parameters is estimated.
- Given a value of sampling time and packet dimension the acquisition process can be continuous over the observation time or may be based on statistical samplings in discrete time intervals. Lead these strategies to equivalent results? Also this influence factor needs to be investigated.
- Measurement results are generally post processed to retrieve more manageable results. The post processing may consist in averages, decimation, peak detection, root mean square calculation, and so on. Then, also the influence of the post processing in the measurement results needs to be accurately investigated.

Among the several above-mentioned QoS indexes, packet jitter plays a very important role. In fact the performance of many real-time services is strictly influenced by this index, especially when a service runs on a complex multi-hop networks where, generally, the data path involves several apparatuses (switches, routers, and so on), protocols and communication medium. Usually these services run on networks that could convey other services. As a consequence the attention of the network manager is often paid to verify if the new class of services can make decay the QoS of the surviving ones. In particular, with reference to the VoIP, a constant packet rate should be assured to provide an adequate QoS, but the presence of additional data traffic (due to the new services) can cause the jitter of the packet arrival times at the receiver, with a possible significant performance deterioration and decay of the QoS [10]. Then, for the VoIP service, the packet jitter is considered as figure of merit and it is required to verify if running the new services imply a significant rise of the packet jitter.

With reference to these issues, starting from the experience in the field [17]-[22], in this paper a deep sensitivity analysis aimed to identify the main quantities influencing the measurement and to estimate the related uncertainty is performed. As an example, the attention has been focused on the packet jitter estimation made on a real test bed, i.e. the local area network of the University of Cassino. It is constituted by an optical fiber based urban ring, of about 10 km, and an extra-urban link of about 140 km. Then the paper aims in investigating about the analytical properties of the jitter to identify simple models that allows the analytical estimation of the measurement uncertainty.

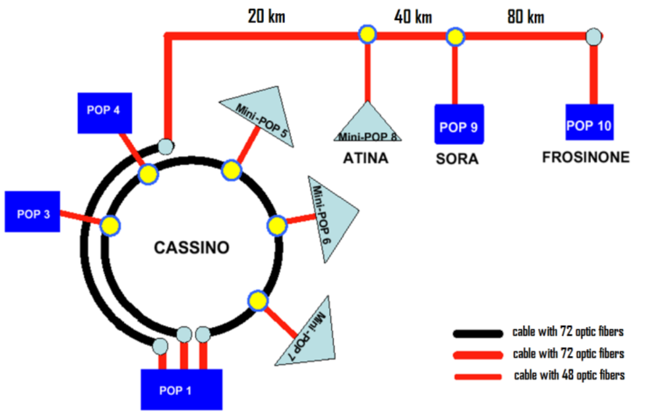


Figure 1. Simplified physical topology of UnicasNet.

In the following, after some general remarks about the test bed the sensitivity of the packet jitter measurement to the considered measurement strategy is preliminary investigated. Then, a statistical model for the evaluation of the uncertainty due to the random contribution is proposed.

II. THE EXPERIMENTAL SETUP

It is a real test bed concerning with the local area network of the University of Cassino (named “UnicasNet”). Its simplified physical topology is reported in Figure 1. It is constituted by an urban ring, of about 10 km, and an extra-urban link of about 140 km. The urban link connects several faculties and offices by means of optic fiber links and active internet devices as switches, routers and servers. A number of Points Of Presence (POP) and Mini POP are suitably employed. In particular, POP 1 provides the link to the geographical backbone and to other extra urban POPs (POP 9, POP 10 and Mini POP 8).

Currently, UnicasNet is used for providing email, internet, and Voice over IP (VoIP) services. In a short period of time, it should be interested by a new class of modern multimedia streaming services as digital video broadcasting and video on demand.

New multimedia services should be distributed by means of typical client server architecture. An example of a client-server architecture from POP 1 to POP 3 is sketched in Figure 2. In particular, for both POPs a hierarchical architecture is involved: starting from the building router, a number of building switches is adopted to establish the link with the several plane switches. The last ones provide the link for the end clients/servers.

As for measurement instrument, a software protocol analyzer, namely the D-ITG (Distributed – Internet Traffic Generator) developed at University of Napoli has been adopted [13]-[15]. It generates a constant packet rate data traffic from a sender station to a receiver one, by using a User Datagram Protocol (UDP). In particular, the default values of constant packet rate (equal to 1000 packets/s), packet size (equal to 512 byte) and inter-departure time packet distribution (rectangular) have been selected on the sender station.

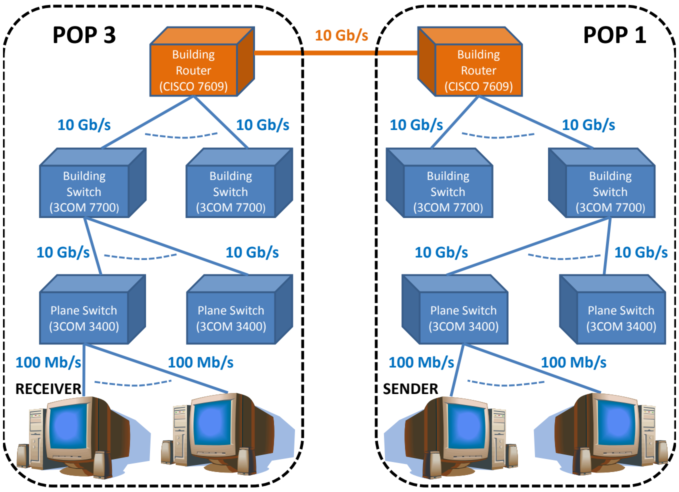


Figure 2. Simplified block diagram of the link POP 3-POP 1.

At the receiver end, the jitter at the instant k is calculated as the average value (over a number of samples, n, automatically selected by the software) of the differences between the packet inter arrival and inter departure times:

$$jitter(k) = \frac{\sum_{i=1}^{n} \left|(R_i - R_{i-1}) - (S_i - S_{i-1})\right|}{n} \tag{1}$$

where R_i and S_i are the arrival and the departure times of the i-th packet, respectively.

To have a detailed jitter analysis, the interval time between two consecutive jitter samples (k+1-k) was equal to 1 ms. Figure 3, reports the measured jitter in time interval long 1800 s.

III. The Sensitivity Analysis

As previously said, an important issue concerning with the measurement method is represented by the post processing algorithm employed to provide a synthetic jitter value at the discrete instant M, $J(M)$, starting from the single packet jitter ($jitter(k)$, with $k=1,..WL$). More in detail, $J(M)$ is generally influenced by two main parameters:

i) The type of estimator employed for achieving $J(M)$;

ii) the window length (which is related to. the time record length), WL, adopted for achieving $J(M)$.

As for i), upon the purpose, a synthetic estimation of $J(M)$ over a time record (which involves a suitable number of jitter samples each one calculated by means of Eq. 1) can be based on the application of different techniques such as:

- Estimation of the linear mean of the jitter samples, evaluated as:

$$J(M) = \frac{\sum_{k=1}^{WL} jitter(k)}{WL} \tag{2}$$

  This estimator is typically employed when the main interest is achieving a mean trend of the figure of merit.

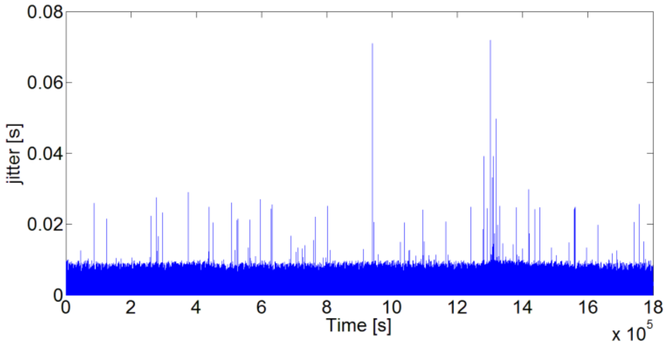


Figure 3. Measured jitter. (Sampling time = 1 ms)

- Estimation of the root mean square of the jitter samples, evaluated as:

$$J(M) = \sqrt{\frac{\sum_{k=1}^{WL} jitter^2(k)}{WL}} \tag{3}$$

  This estimator is typically employed when the interest is achieving a measure of the energy associated to the figure of merit.

- Numerical decimation of the jitter samples, evaluated as:

$$J(M) = jitter(k)\big|_{k=M \cdot WL} \tag{4}$$

  This estimator is typically employed when the interest is achieving small acquisition record lengths and simple processing routines.

As for ii), the window length, WL, adopted in the evaluation of $J(M)$, influences the capability of the selected estimator in tracking the figure of merit evolution rather than filtering the high frequency components: as well known, the higher is the number of samples (on which the estimator is calculated), the higher is the filtering noise degree and the lower is the possibility of tracking the figure of merit evolution. In the case of the packet jitter, these aspects are more and more critical since the measurand can exhibit a large behaviors variety.

The influence of both parameters on the evaluation of J has been analyzed by varying WL in{1, 2, 5, 10, 20, 50, 100, 200, 500, 1000}. For a sake of readability, Fig. 4 reports the evolution of $J(M)$ in a 1 s-width time interval, for the three estimators defined in Eqq. 2-4, considering only WL equal to 2, 50, 200, 1000.

Analyzing the results reported in Fig. 4, it is possible to highlight as the WL seems to influence the jitter estimates for each estimator. This is due to the jitter evolution in the considered time window, which is characterized by long-time interval in which high fluctuations around a mean value are observed.

As for the decimation estimator, as expected, the influence of WL is more evident.

Figure 5 reports the evolution of $J(M)$ in a 1 s-width time interval (the same of Fig. 4), for the three estimators defined in Eqq. 2-4, fixing the WL equal to 2, 20, 200, respectively. Analyzing the obtained results it is possible to affirm that given a value of WL, the choice of the estimator can bring to

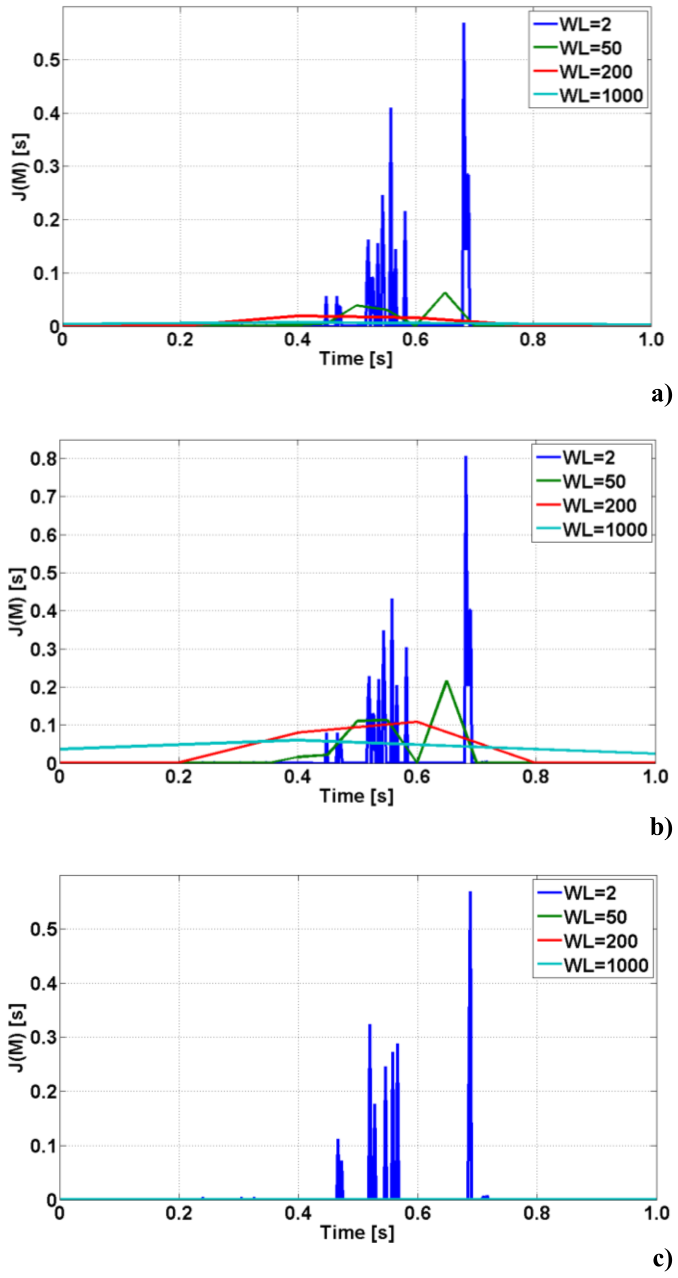


Figure 4. Comparison of different jitter estimators for different *WL*: a) Linear Mean, b) Decimation, c) RMS, considering a 1 s-width time interval around 12004 s.

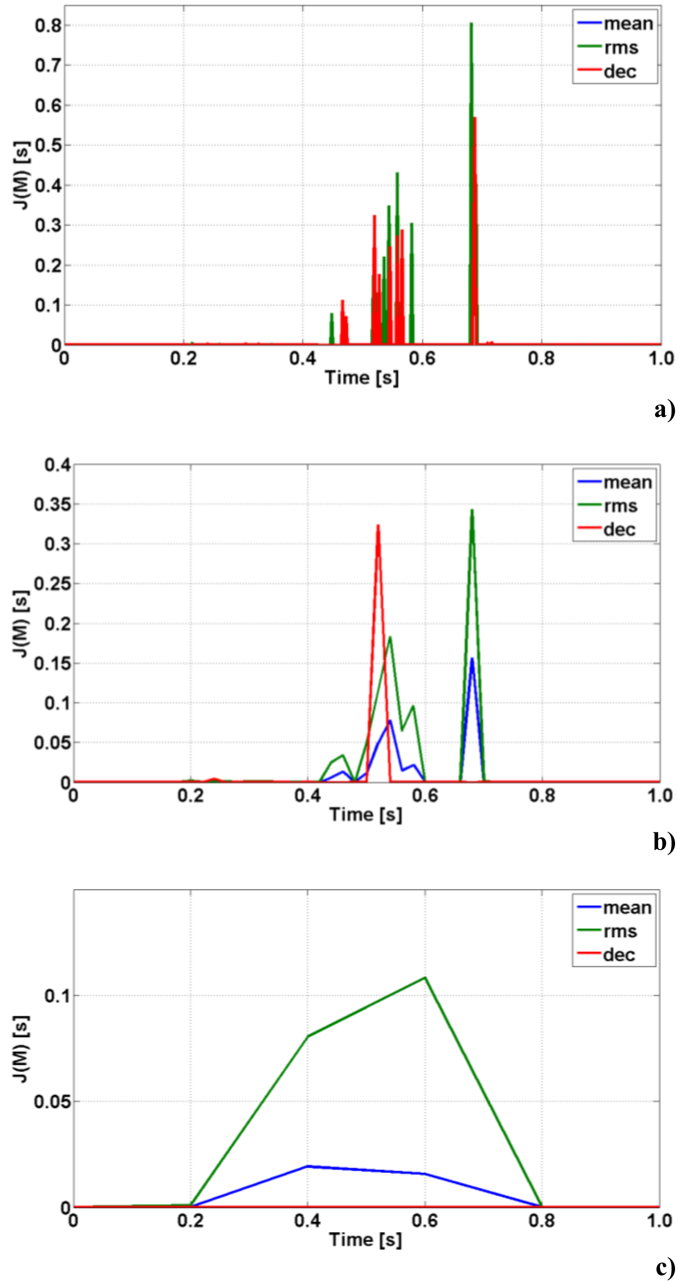


Figure 5. Comparison of different jitter estimators for different *WL*: a) WL=2, b) WL=20, c) WL=200, considering a 1 s-width time interval around 12004 s.

significant differences in jitter values, and this phenomenon is more and more evident as *WL* increases. This is highlighted by the synthetic indexes reported in Table I which are referred to all data set of 18000 s. In particular, for each value of *WL*, the percentage mean deviation, $\Delta_{M,Y}\%$ (evaluated by Eq. 5), and its corresponding standard deviation, $\sigma_{M,Y}\%$, between the mean estimator, *M*, and the other ones, *Y*, are reported.

$$\Delta_{M,Y}\% = \frac{1}{S}\sum_{i=1}^{S/WL}\frac{\left(M(i)-Y(i)\right)}{M(i)}\cdot 100 \qquad (5)$$

Table I shows that the three considered estimators bring to similar results (if we consider the average deviation) only for small values of *WL*. As *WL* increases, $\Delta_{M,Y}\%$ and $\sigma_{M,Y}\%$ quickly diverge.

The results obtained by this preliminary sensitivity analysis prove that the selection of the type of estimator and window length on which the related quantity is evaluated can bring to significant different results in the measurement of packet jitter. In addition, it has been shown that the influence of these parameters depend also on the variability features of the measurand. As a consequence, these parameters can be thought as measurement uncertainty sources and then they should be taken into account in the overall measurement uncertainty.

TABLE I. COMPARISON OF DIFFERENT ESTIMATORS (M=LINEAR MEAN, R=RMS, D=DECIMATION)

WL	$\Delta_{M,D}$%	$\sigma_{M,D}$%	$\Delta_{M,R}$%	$\sigma_{M,R}$%
2	-3.13	74	-23.3	17.2
5	-1.61	101	-39.3	23.3
10	-3.81	127.4	-52.6	33.5
20	-2.96	158.4	-69.4	55.5
50	-8.15	196.7	-92.99	87.89
100	-7.70	244.3	-116.4	115.3
200	-5.46	268.5	-153.5	146.9
500	-44.9	630.4	-234.21	174.6
1000	-51.1	663.81	-247.8	181.9

IV. THE PROPOSED APPROACH FOR THE UNCERTAINTY ESTIMATION

Generally, the variability of packet jitter measurements is due to two main classes of phenomena [23]: those related to the measurement chain and those related to the measurement settings.

As for the former, they are mainly due to the intrinsic variability of the measurement set-up introduced by several components such as:

1) repeatability of the reference traffic generator and measurement nodes (hardware and software components);

2) measurement system resolution;

3) measurement system noise floor;

4) repeatability of the involved network devices (routers, switches and so on);

5) repeatability of the communication medium involved;

6) presence of network background traffic (services and applications running on the networks during the measurement campaign).

As for the latter, they are mainly due to:

7) transmission traffic settings (packet size, traffic rate, packet inter-departure time);

8) measurement settings (the estimator adopted for the evaluation of the figure of merit, the record length on which the estimator is evaluated, the time instant at which the measurement starts).

Items 1)-6) can be associated to suitable uncertainty components which can be properly combined to achieve the overall measurement uncertainty. In addition, as better explained after, the items 1)-6) can be thought as dependent function of the variability sources related to items 7)-8).

To identify and quantify the uncertainty contributions due only to the measurement settings, a statistical approach based on a suitable experimental campaign is proposed.

In the following it is assumed that the jitter is described by the estimator above described and calculated over N samples, namely $e(N)$, where N is the record length adopted. Named M the total number of available samples (collected over a suitable record length), and $L = M/N$ the number of steps needed to cover with N length windows the whole M length sample record, the measurement uncertainty can be estimated as:

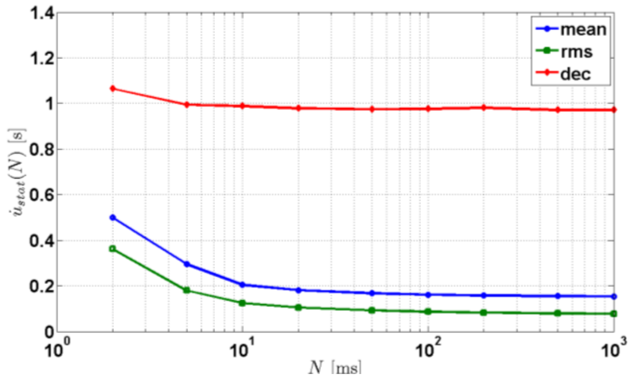


Figure 6. Evaluation of the relative uncertainty for the three considered estimators versus the *WL* (*N*).

$$u_{stat}(N) = \sqrt{u_e^2(N) + u_{\sigma e}^2(N)} \tag{1}$$

where:

- $\sigma e(N)$: the standard deviation of the L values of $e(N)$;
- $u_e(N)$: the uncertainty due to the variability of the L values ($e(N)$), estimated as $\sigma e(N)$;
- $u_{\sigma e}(N)$ is the uncertainty due to the variability of the L standard deviations ($\sigma e(N)$), estimated as standard deviation of $\sigma e(N)$.

All the uncertainty contributions have been considered as uncorrelated. Then, for a considered value of N, the function u_{stat} synthesizes the random contributions due the repeatability of all items 1)-8).

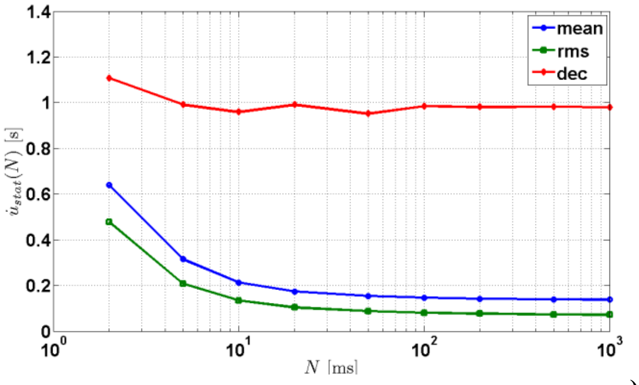
The behavior of the relative uncertainty, ı̇ , obtained by considering the three above mentioned estimators is shown in Figure 6. For the evaluation of these uncertainties several values of N have been considered, in particular N= {1, 2, 5, 10, 20, 50, 100, 200, 500, 1000}.

To verify the generality of the obtained results, the same analysis was performed for two new measurement campaigns carried out in different days with respect to the previous one. The related results are shown in Figure 7.

In all cases, it is possible to highlight that the rms estimator shows the best uncertainty values for each considered values of N. Instead the jitter estimate obtained by the operation of decimation are characterized by the worst uncertainty that is also equal around 100% of the estimated value.

V. CONCLUSION

The analyses reported in this paper have shown that the type of estimator adopted for the jitter evaluation as well as the record length on which the value is calculated significantly influence the results. In particular, the filter effect due to the increasing of the record length is more evident for decimation and rms estimators.



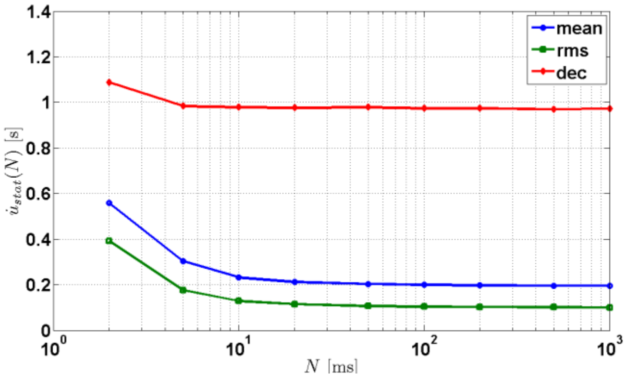


Figure 7. Evaluation of the relative uncertainty for the three considered estimators versus the *WL* (*N*). (Two further measurement campaigns are involved)

The proposed model for the evaluation of the uncertainty due to the random contribution have shown that the rms estimator provides the smallest variability whilst the decimation one is characterized by the worst behavior.

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