Shared Congestion Detection: A Comparative Study

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Abstract:

Most Internet-tomography problems such as shared congestion detection depend on network measurements. Usually, such measurements are carried out in multiple locations inside the network and relied on local clocks. These clocks usually skewed with time making these measurements unsynchronized and thereby degrading the performance of most techniques. Recently, shared congestion detection has become an important issue in many computer networked applications such as multimedia streaming and peer-to-peer file sharing. One of the most powerful techniques that employed in literature is based on Discrete Wavelet Transform (DWT) with cross-correlation operation to determine the state of the congestion. Wavelet transform is used as a de-noising tool to reduce the effects of both clock skew and queuing delay fluctuations on the decision of congestion type. Since, classical Discrete Wavelet Transform (DWT) is not shift-invariant transform which is a very useful property particularly in signal de-noising problems. Therefore, another transform called Stationary Wavelet Transform (SWT) that possesses shift-invariant property is suggested and used instead of DWT. The modified technique exhibits a better performance in terms of the time required to correctly detect the state of congestion especially with the existence of clock skew problem. The suggested technique is tested using simulations under different environments.

Keywords: shared congestion, clock skew, shift invariant, cross correlation, soft-threshold operation.

الخلاصة:

معظم الدراسات التي تهتم بحل مشاكل شبكة الأنترنت ككشف الأختناق المشترك تعتمد على اجراء قياسات معينة لعوامل الشبكة. هذه القياسات عادة ما تنجز في أماكن مختلفة داخل الشبكة معتمدة في ذلك على مؤقتات داخلية. هذه المؤقتات عادة ماتتعرض الى أنحراف بمرور الوقت مما يؤدي الى عدم تزامن هذه القياسات وبالتالي هبوط في أداء كثير من هذه التقنيات. ان عملية اكتشاف الأختناق المشترك قد أصبحت مؤخرا من الأمور المهمة في كثير من تطبيقات شبكات الحاسوب. على سبيل المثال لا الحصر، تبادل الملفات المتعددة الوسائط (الصوت والصورة) وكذلك المشاركة البينية في تبادل الملفات. واحدة من أفضل هذه التقنيات المستخدمة تعتمد في عملها على المحول ذو المويجة المتقطعة (DWT) مع معاملات التشابه المتناظرة لتحديد نوع الأختناق. يستخدم المحول كأداة للتخاص من تأثيرات كلا من انحراف المؤقت المستخدم في قياس عوامل التأخير وكذلك تذبذب عوامل التأخير الناتج بسبب وجود وحدات الخزن على عملية تحديد نوع الأختناق. ولكن بسبب كون هذا المحول لا تتمتع مخرجاته بخاصية عدم التأثر بالتزحيف والتي تعتبر من الخواص المفيدة وخصوصا في تطبيقات ازالة الضوضاء من الأشارات المختلفة. لذلك تم أقتراح أستخدام محول أخر يدعى المحول ذو المويجة المستقرة (SWT) والذي يمتاز بخاصية عدم التأثر بتزحيف البيانات ليحل محل المحول السابق. أظهرت التقنية المعدلة أداءا أفضل من حيث الوقت المستغرق في عملية الأكتشاف وكذلك الدقة وخصوصا مع وجود خطأ في المؤقت. تم تجريب التقنية المقترحة وبنجاح في ظروف مختلفة.

Introduction

Congestion control is the mechanism that was widely credited with the stability of the service of the internet. Without such mechanism, internet or any other network cannot be survived. In the first generation of internet services that mostly consist of file transfers, congestion control mechanisms are applied per flow without any feedback from the other flows that share the resources of the network. To these services, it is considered adequate.

With the emerging of new services that need a lot of bandwidth and more sensitive to network delay and packet loss, applying congestion control techniques per flow may lead to service degradation. And therefore, the principle of cooperation congestion control is appeared. This concept exhibits a better performance than the older techniques that control the congestion for each flow alone.

The concept of congestion control cooperation is very simple and can be comprehended from the following real situation. Car traffic in any crowded city can be used as a good example to demonstrate the concept. If the car drivers are very selfish and aiming in any method to reach their destinations, without caring of the others, the jam will be terrific, especially in the intersections of the main roads (routers in our problem). However, if the drivers are cooperated between themselves and listen to the instructions of the traffic men, the situation will be better. As a result, the movement of cars will be smoother than before and the jam condition will be of less severity. This is because, the resources are limited and the users of those resources are unlimited. Therefore, the cooperation between users in exploiting the resources decreases the hardness of the situation and enhances the performance.

The same scenario exists in computer networks. Therefore, the cooperation means that the decision is taken according not only to the condition of the flow but from all the flows that share the resources. Hence, the detection of resource sharing especially in the existence of congestion is a significant issue that enhances the performance of the network. The information of shared congestion detection can be used to change the path of packets or to modify the topology of the network in overlay systems.

In general, the operation of inferring shared congestion depends on the feedback information of link delay or packet loss rate or both. Previous works exhibit the robustness of methods that rely on link delay over the methods that depend on packet loss [Rubenstein 2002]. One of the most powerful methods that depend on the delay of the packets as a measure to detect shared congestion is the method presented in [Kim 2008]. The method uses a digital signal processing technique to extract the required information from link delay measurements and uses cross-correlation coefficients to estimate the type of congestion. The method uses discrete wavelet transform as a de-noising tool to isolate the useful information from the delay of the packets and deliver this information to the cross-correlation function.

There are two factors that affect the output of cross-correlation, and thereby, the process of shared congestion detection. These effects corrupt link delay measurements and mislead cross-correlation function. The first factor is the queuing delay fluctuations. This factor is mainly due to the random behavior of the buffers that exist in the routers. The second factor is the effect of clock skew that makes link delay measurements out of synchronization.

To get rid of all these effects, the measurements should be de-noised by threshold the wavelet detail coefficients. However, DWT is not shift invariant transform. Shift variant property means that there is no simple relationship between wavelet coefficients of the signal and those of the delayed version of it [Pesquet 1996]. Therefore, clock skew problem could cause false detection. That is, clock skew might mislead cross-correlation function and change the condition from shared to independent congestion. Therefore, a modification to the technique used in [Kim 2008] is suggested to completely remove the effect of clock skew.

Recently, Stationary Wavelet Transform (SWT) is used successfully in the literature especially in signal de-noising, image de-noising and signal detection [Zikov 2002],[Brychta 2007],[Solbo 2008],[Hai 2009], and [Kubinyi 2011]. The main advantage of SWT is its shift invariant property [Lang 1996]. Using SWT instead of DWT to detect shared congestion has revealed a better performance especially with the existence of clock skew problem, as we will see in the simulation results. The only drawback of SWT is its computation complexity of order N logs (N) compared to only N for DWT, where N represents the number of samples.

Shared Congestion Detection Using Cross-Correlation Coefficients:

Fig.1 shows the network topology that shared congestion is mainly happened. The link(s) between nodes s and t is (are) shared. To detect shared congestion, packets will be sent with time stamps from node xt to the node xr. At node xr the packets are again time stamped and resent to node xt. For each packet, the difference between the two time stamps represents the time of the journey (time delay). The same thing is done for the two nodes yt and yr. At the end of the experiment, two delay sequences x and y are obtained for the two paths.

Then after, using the cross-correlation function of eq. (1), the condition of the network could be determined [Kim 2008]:

$$XCOR = \frac{\sum_{i=1}^{n}(xi-\bar{x})(yi-\bar{y})}{\sqrt{\sum_{i}^{n}(xi-\bar{x})^{2}\sum_{i}^{n}(yi-\bar{y})^{2}}} \qquad (1)$$

Where: n represents the length of the sequences x and y; $\bar{x}$ and $\bar{y}$ represent the mean values of x and y, respectively.

The key idea behind using cross-correlation coefficient in detecting shared congestion returns to the fact that says; packets that pass through the same congested points possess similar time delay and loss rate patterns [Rubenstein 2002].

For network topology used in this paper, the measured delays consist of two parts. The 1st one is due to packet passing through the shared link between nodes s and t. The other is due to packet passing through the unshared links.

The main property of cross-correlation function, its value is dominated by the most dynamic part of the delay sequence [Kim 2008]. Three cases could happen. If the traffic is light (no congestion in all links), the pattern of the delay sequences has uncorrelated noise-like spikes with small delay values as shown in **Fig.2**. And, the value of XCOR is around 0.5. This case was not taken into consideration in [Kim 2008]. Neglecting this case could cause false decisions, since; the value of XCOR is very near to the selected threshold value that distinguishes shared congestion from independent one.

If congestion happens in the links between nodes s and t, the delay sequences are highly correlated with pulse like patterns of large amplitudes as shown in **Fig.3**. Therefore, XCOR value approaches 1. If the congestion happens in the unshared links, the pattern of the delay sequences are consist of both pulse-like spikes with large amplitudes and noise-like spikes with small amplitudes as shown in **Fig.4**. It is clear from the figure that the two delay sequences are out of phase and uncorrelated. Hence, XCOR value approaches 0.

Stationary Wavelet Transform (Swt):

One of the drawbacks of the Discrete Wavelet Transform (DWT) is being a shift-variant transform. Shift-variant means that the transform of the delayed version of the signal is not linearly related to the transform of the original signal. Shift-invariant property is very important in many applications such as signal de-noising, image de-noising, signal detection and function estimation.

In normal DWT, the signal of length N is convolved with a LPF h and a HPF g. Then, the output of each filter is down sampled (decimated) by 2 to produce two sequences of N/2 length. One sequence represents the approximation coefficients (LPF branch) and the other represents the detail coefficients (HPF branch). The relation between the filters g and h defines what is called Quadrature Mirror Filter (QMF) [Vetterli 2007]. These coefficients represent first level decomposition of the original signal. To obtain 2nd level coefficients, the approximation coefficients of the previous level (1st level) is convolved again with the same filters g and h to get detail and approximation coefficients of the 2nd level (of length N/4 each). Similarly, detail and approximation coefficients could be obtained for the levels 3, 4, 5, etc.

The decimation operation is necessary to get a non-redundant representation of the signal. But the cost is losing the shift-invariant property of the DWT. Researchers made several

Modifications to the classical DWT to regain shift-invariant property. One of the most powerful algorithms is the Stationary Wavelet Transform (SWT) or sometimes called Shift Invariant Discrete Wavelet Transform [Nason 1995].

The main difference between DWT and SWT is that the signal after convolution with g and h filters is not down sampled by 2. Instead, the filters g and h are up sampled by 2 (starting from the 2nd level). The result of that, the length of both detail and approximation coefficients is the same as the length of the applied signal. In other words, the length of the coefficients of the 1st level decomposition is twice the length of the original signal. Therefore, the signal is of redundant representation. Hence, SWT is sometimes called Non-Decimated Discrete Wavelet Transform. This redundancy preserves shift-invariant property. The cost is increasing the computational complexity and losing the orthogonally of the transform. Losing orthogonally means that the inverse SWT is not unique and could be evaluated using all decimation combinations and then averaged [Nason 1995]. **Fig.5** below gives a schematic view of DWT and SWT.

Signal De-Noising Using Non-Linear Threshold Operation:

Any signal de-noising problem can be stated mathematically as follows:

$$\bar{x}(n) = x(n) + e(n) \qquad (2)$$

where n is an integer number, $x(n)$ is the noise-free signal, $\bar{x}(n)$ is the measured (corrupted) signal, $e(n)$ is the noise.

In literature, many techniques are used for de-noising purposes. One of the most known methods is the non-linear threshold operation. Threshold operation could be employed through soft or hard threshold operation. In this work, soft threshold is employed, since; this technique guarantees smoothness of the de-noised signal to the same degree of the smoothness of the original signal [Donoho 1995].

Soft threshold operation is performed on detail coefficients only as follows: If the coefficients are less than some threshold value, The coefficients are killed to zero; otherwise, the coefficients are shrunk by the value of the threshold. The following relationship explains soft threshold operation mathematically [Donoho 1995]:

$$d_T = \begin{cases} d - T & if\, d \geq T \\ d + T & if\, d \leq -T \\ 0 & if\, |d| < T \end{cases} \qquad (3)$$

Where T is the threshold value; d_T represents the detail coefficients after threshold.

There are many approaches to determine the value of the threshold T. In this work, the following equation is used to estimate the threshold value [Donoho 1995]:

$$T = \sqrt{2 \times \epsilon \times log_e(N)} \qquad (4)$$

Where N is the number of samples and ϵ is the noise variance.

Simulation and Results:

At the beginning, simulations are carried out on the 3-node network topology shown in **Fig.6** using network simulator NS2. For comparison purposes, the experiment setup is similar to that in [Kim 2008]. The bandwidth of each link is 1.5 Mb/s. The propagation delay is chosen randomly between 20 and 30 msec for each simulation. The background traffic is a pareto ON-OFF constant bit rate (CBR) flow with a pareto shape parameter of (1.2). The average ON and OFF times are 0.2 and 3 sec, respectively. CBR rate is selected uniformly between 20 Kb/s and 40 Kb/s for each simulation. Therefore, the level of congestion could be controlled through the number of CBR flows on each link. The duration of each simulation is 100 sec. To acquire the delay sequences, UDP probe packets are sent at rate of 10 Hz for duration of 100 sec. Also, the bases functions used in denoising are db6.

A. Shared Congestion Detection Experiment:

To simulate shared congestion state, background traffic of 100 CBR flows is initiated on the shared link and 60 CBR flows on the other links. The simulation is repeated for 500 times. **Fig.7** depicts XCOR values of the de-noised delay sequences using DWT and SWT. These values represent the average of the 500 simulations. It is clear from the graph that XCOR with SWT is faster than XCOR with DWT. XCOR-SWT needs less than 2 sec to reach the correct decision. Whereas, XCOR-DWT technique requires no less than 100 seconds to reach the same value of cross-correlation of XCOR-SWT.

Furthermore, to prove the validity of the proposed technique, simple mathematical calculations would be used. The former technique needs about 10 seconds to correctly detect shared congestion as stated in [Kim 2008]. This means, about 100 probe packets are needed to achieve the task. Since the computational complexity of DWT is proportional to the number of packets, therefore, evaluating DWT requires a computational power of order 100 operations. Whereas, the modified technique that depends on SWT needs about 1.6 seconds (only 16 probe packets) to detect correctly shared congestion. Hence, the computational power of the modified technique is of order 16 ×Log (16) = 19 only. In addition, it is clear that the evaluation of cross-correlation coefficient for 16 packets needs fewer operations than for 100 packets.

B. Independent Congestion Detection Experiment:

To simulate independent congestion state, background traffic of 60 CBR flows is initiated on the shared link and 100 CBR flows on the other links. Also, the simulation is repeated for 500 times. **Fig.8** draws XCOR averaged values of the de-noised delay sequences using DWT and SWT.

It is obvious; the behavior of XCOR-SWT in detecting independent congestion is comparable to XCOR-DWT especially for the first 10 seconds as expected. Since, the delay sequences of the two paths are completely uncorrelated. That is, at independent congestion, the noise has nothing to do with time delay measurements and even if the sequences are not de-noised, XCOR values approach zero at the same performance, approximately. Although, cross-correlation coefficient values of DWT-de-noised sequences are more closer to zero than those de-noised by SWT. Because, shift-invariant property of SWT has an averaging effect on the data. Consequently, the de-noised delay sequences are little over-smoothed and, thereby, are more correlated than before. This makes cross-correlation coefficient values of SWT-de-noised sequences are somewhat greater than those of DWT-de-noised sequences. Also, the figure shows that XCOR coefficients of the SWT–de-noised sequences are more stable than the coefficients of the DWT–de-noised sequences, because, the bases functions of DWT are more time-varying than those of the SWT.

C. Shared Congestion Experiment With Clock Skew:

To evaluate the effect of clock skew on the decision of the type of congestion, the following is done: One of the delay sequences is shifted by an offset δt with respect to the other delay sequence. δt represents the time deviation between the two clocks on which time delays are sampled. Then, only the overlapped portion of the two sequences is used to identify the state of the congestion. This procedure is applied on the delay sequences that are obtained from the "**shared congestion detection experiment**". **Fig.9** draws the behavior of the two techniques (XCOR-DWT and XCOR-SWT). In this graph, the usefulness of time-invariant property of SWT is obvious. The effect of clock skew on XCOR-SWT is negligible compared to the performance of XCOR-DWT.

D. Simulations With More Realistic Topologies:

Computer networks in real life are more complex than the network used in the previous simulations. Therefore, another set of simulations in a more challenged environment should be conducted in order to investigate the robustness of the suggested technique compared to the previous one

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Practically, most network traffics in the internet are carried out using TCP as a transport protocol. Therefore, the next simulations will include both traffic types; TCP and UDP traffic flows.

Moreover, all the simulations will be achieved in a more realistic network topology that shown in **Fig.10**

D.1 Simulations with TCP Traffics:

The experiment setup consists of the following:

1. Shared congestion case: For each simulation, a link is randomly chosen from the shared links (links 1, 2, & 3) and background traffic of 20

2. file transfer TCP flows is created to cross the intended link. The other unshared links (links 4,5,6,7, & 8) are left idle.
3. Independent congestion case: The shared links are left idle and the non-shared links are traversed by background traffic of a number of TCP flows that is selected randomly from 0 to 20 for each simulation.

In both cases, the simulation is repeated for 500 times. The averaged performance of the suggested technique is depicted pictorially in **Fig.11** and **Fig.12**.

The values on the y-axis represent the "Positive Ratio". This metric will be used to measure the performance of the technique. Positive Ratio could be defined as the ratio of the number of answers indicating shared congestion to the number of experiments [Kim 2008]. This metric will approach to 1 if the experiment involves shared congestion and will approach to 0 in the case of independent congestion. The threshold that would be used to differentiate XCOR values of shared congestion from independent congestion is 0.512[Kim 2008]. **Fig.13** shows the effect of clock skew on the performance of both techniques with TCP flows.

D.2 Simulations with UDP Traffics:

The experiment setup consists of the following:

1. Shared congestion case: In this case, a 100 ON-OFF constant bit rate (CBR) flows is initiated in one of the shared links (slected randomly for each simulation). The number of background traffic flows on the other links is chosen randomly from 31 to 70.
2. Independent congestion case: The shared links are traversed by a number of CBR flows that is chosen randomly from 31 to 70. The other links are occupied by a background traffic of CBR flows of a number selected randomly from 61 to 100.

In both cases, the experiment is repeated for 500 times. **Fig.14** and **Fig.15** summarized the averaged performance of the suggested technique compared to the previous one.

Fig.16 shows the effect of clock skew on the performance of both techniques with CBR flows.

Conclusions:

In this work, a comparison study is made between Discrete Wavelet Transform (DWT) and Stationary Wavelet Transform (SWT) in a signal de-noising problem. These two transforms are used with the Cross-Correlation function to identify the state of the congestion in a network of a known topology. This study reveals that signal de-noising using SWT is more accurate than signal de-noising using DWT. This makes shared congestion detection using XCOR-SWT faster than XCOR-DWT. Therefore, the modified technique pumps the network with fewer probe packets than the former technique. Also, the results shows that signal denoising using SWT is more robust against network dynamics than DWT. This property could be noticed from the different Positive Ratio curves and for both types of traffics.

The main contribution of this work is completely eliminating the effect of clock skew on shared congestion detection. This effect could mislead detection process and might change the state of the network from shared congestion to independent congestion. The only disadvantage of Stationary Wavelet Transform, it consumes more computational power than Discrete Wavelet Transform for the same no. of samples. This drawback is neutralized, since; XCOR-SWT technique detects shared congestion faster than XCOR-DWT, as shown in the results.

References:

[Brychta 2007] Robert J. Brychta, Sunti Tuntrakool, Martin Appalsamy, Nancy R. Keller, David Robertson, Richard G. Shiavi, and André Diedrich," Wavelet methods for spike detection in mouse renal sympathetic nerve activity", IEEE Trans. Bio. Eng., Vol. 54, No. 1, pp.82-93, Jan. 2007.

[Donoho 1995] David L. Donoho, "De-noising by soft-thresholding", IEEE Trans. Infor. Theory, Vol. 41, No. 3, pp.613-627, May 1995.

[Hai 2009] Liu En-Hai, Liu Hong-Pu, Zhang Yan, and Guo Zhi-Tao," An improved method of image denoising based on stationary wavelet" , GCIS '09, WRI Global Congress on Intelligent Systems , pp.379-383, 2009.

[Kim 2008] M. S. Kim, T. Kim, Y. Shin, S. S. Lam, and E. J. Powers," A wavelet-based approach to detect shared congestion", IEEE/ACM Trans. Net., Vol. 16, No. 4, pp.763-776, Aug. 2008.

[Kubinyi 2011] Michal Kubinyi, Ondrej Kreibich, Jan Neuzil, and Radislav Smid," EMAT noise suppression using information fusion in stationary wavelet packets", IEEE Trans. Ultra., Ferro., and Freq. Con., Vol. 58, No. 5, pp.1027-1036, May 2011.

[Lang 1996] M. Lang, H. Guo, J. E. Odegard, C. S. Burrus, and R. O. Wells, Jr., "Noise reduction using an un-decimated discrete wavelet transform", IEEE Signal Processing Letters, Vol. 3, No. 1, pp. 10-12, Jan. 1996.

[Liu 2007] Xiaolei Liu, A. H. Osman, and O. P. Malik, "Stationary wavelet transform based HVDC line protection", 2007 39th North American Power Symposium (NAPS' 2007).

[Nason 1995] G. P. Nason and B. W. Silverman, "The stationary wavelet transform and some statistical applications", Lecture Notes in Statistics, Vol. 103, pp. 281-299, 1995.

[Pesquet 1996] J. C. Pesquet, H. Krim, and H. Carfantan, “Time invariant orthonormal wavelet representations,” IEEE Trans. Signal Processing, Vol. 44, No. 8, pp.1964-1970, Aug. 1996.

[Rubenstien 2002] D. Rubenstein, J. Kurose, and D. Towsley," Detecting shared congestion of flows via end-to-end measurement", IEEE/ACM Trans. Net., Vol. 10, No. 3, pp.381-395, Jan. 2002.

[Solbo 2008] Stian Solbo and Torbjorn Eltoft," A stationary wavelet-domain wiener filter for correlated speckle", IEEE Trans. Geo. Rem. Sen., Vol. 46, No. 4, pp.1219-1230, Apr. 2008.

[Vetterli 2007] Martin Vetterli and Jelena Kovačević, Wavelets and Sub-band Coding, published by Prentice Hall PTR, Englewood Cliffs, New Jersey, 2007.

[Zikov 2002] Tatjana Zikov, Stkphane Bibian, Guy A. Durnont, Mihai Huzmezan, Craig R. Ries," A wavelet based de-noising technique for ocular artifact correction of the electroencephalogram", Proceedings of the Second Joint EMBS/BMES Conference, Houston, USA, Oct. 2002.

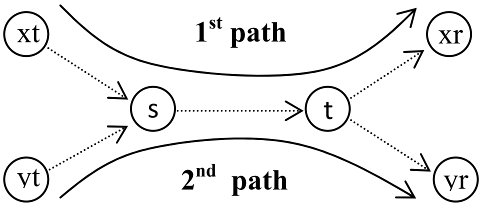


Fig.1: Network topology that is used to study shared congestion.

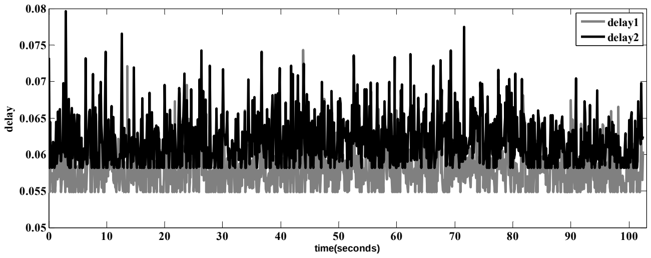


Fig.2: The two link delay patterns when the traffic is light.

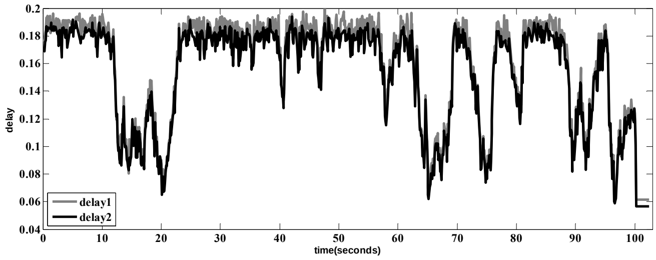


Fig.3: The two link delay patterns with shared Congestion.

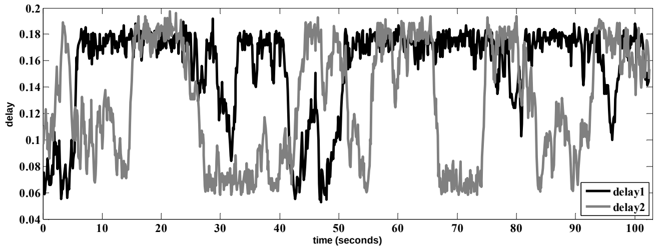
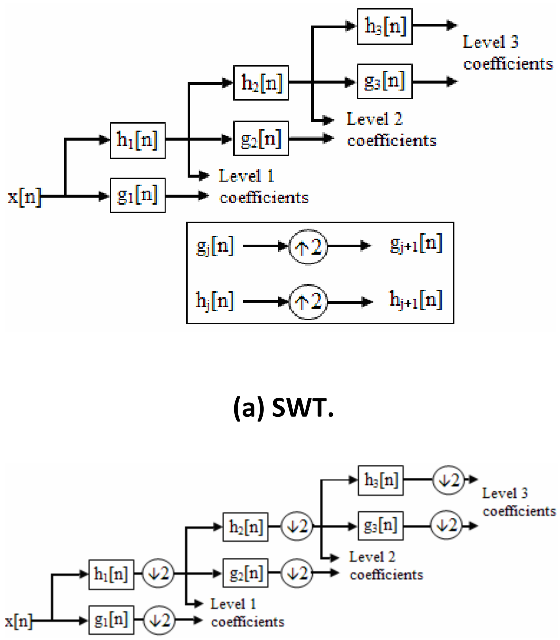


Fig.4: The two link delay patterns with independent congestion.



(a) SWT.

(b) DWT.

Fig.5: Stationary and discrete wavelet transforms [Liu 2007].

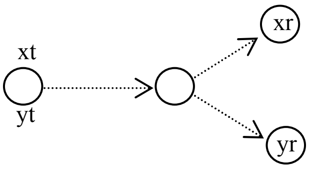


Fig.6: Network topology that is used in the simulation.

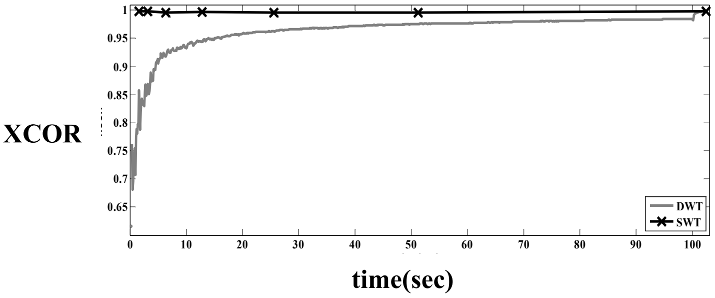


Fig.7: XCOR coefficients of the de-noised sequences using SWT and DWT for the shared congestion experiment.

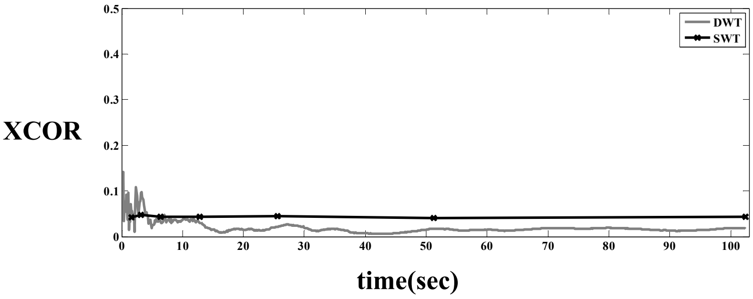


Fig.8: XCOR coefficients of the de-noised sequences using SWT and DWT for the independent congestion experiment case.

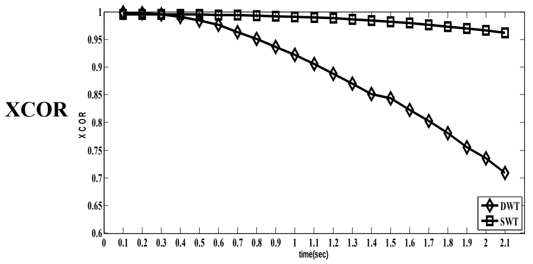


Fig.9: The effect of clocks skew on the XCOR coefficients of both SWT and DWT de-noised sequences.

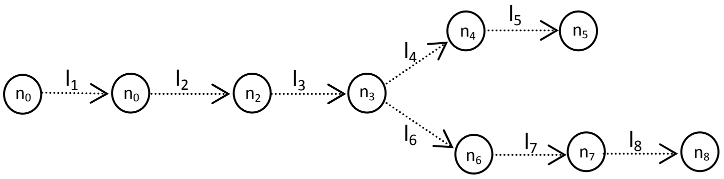


Fig.10: Network topology with multi-shared links.

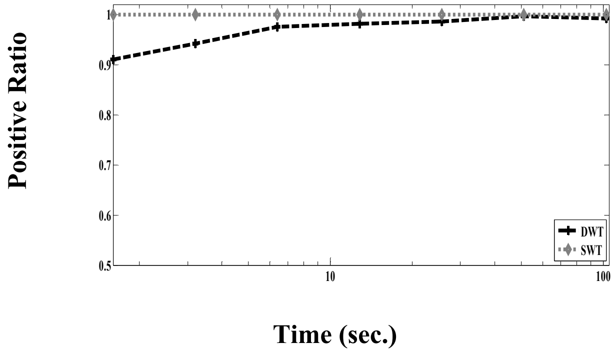


Fig.11: Positive ratio for TCP traffic with shared congestion case.

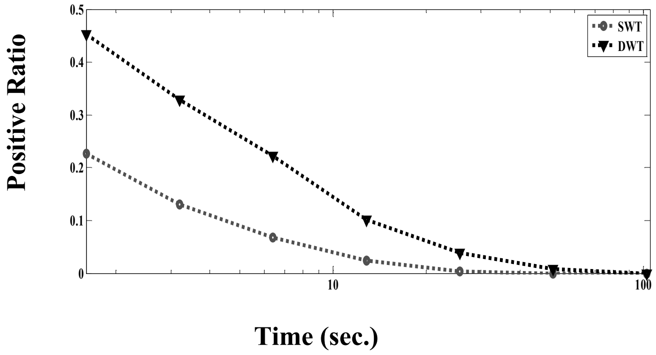


Fig.12: Positive ratio for TCP traffic with independent congestion case.

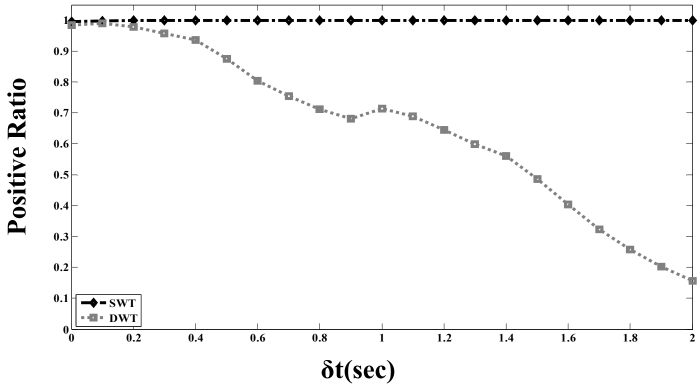


Fig.13: The effect of clock skews on both techniques for TCP traffics.

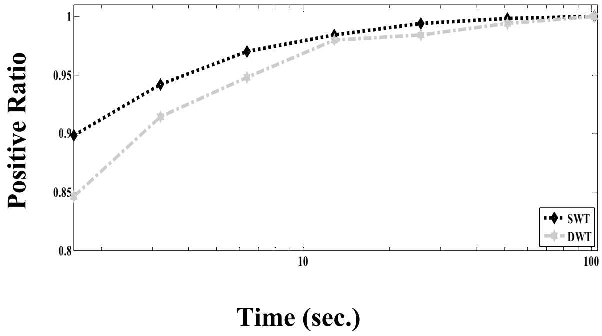


Fig.14: Positive ratio for UDP traffic with shared congestion case.

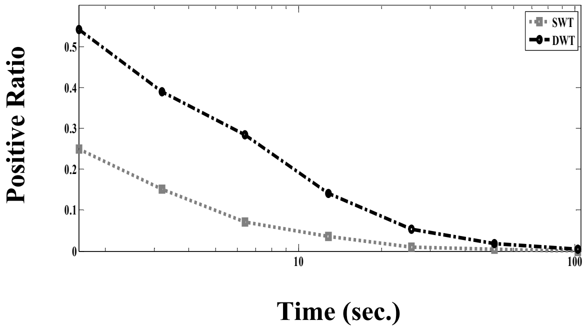


Fig.15: Positive ratio for UDP traffic with independent congestion case.

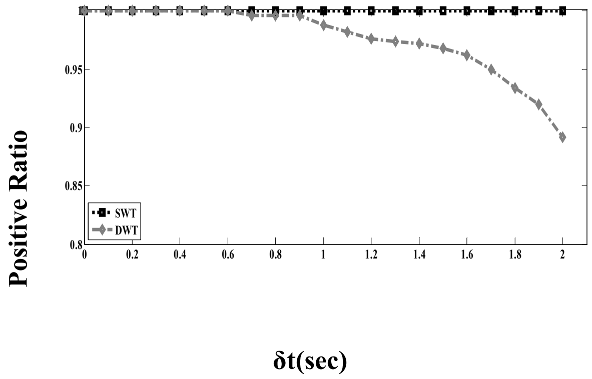


Fig.16: The effect of clock skews on both techniques for UDP traffics.