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A SMART VPN BONDINGTECHNIQUE BASEDON RTT ANALISYS AND NEURAL NETWORK PREDICTION

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Internet mobile networks are not designed to support the real-time data traffic due to many factors as resource sharing, traffic congestion, radio link, coverage, etc., which affect the Quality of Experience (QoE). A possible solution to improve the QoS in mobility scenarios, is given by the "Smart VPN Bonding" technique, which is based on aggregation of two or more internet mobile accesses and is able to provide a higher end-to-end available bandwidth due to an adaptive load balancing algorithm. In this paper, in order to dynamically establish the correct load balancing weights of the smart VPN bonder, a neural network approach to predict the main Key Performance Indicators (KPIs) values in a determinate geographical point is proposed. More specifically, the paper investigates the relation between the Round Trip Time (RTT) and the end-to-end available bandwidth (upload and download) in order to simplify and speed up the estimation bandwidth process.

Keywords: Smart VPN Bonding, Bandwidth prediction, QoS improvement, Neural Network.

1. Introduction

Nowadays the use of mobile Internet services, namely the use of Internet services through the data access offered by different cellular providers has experienced a significant increase. This increase is certainly due to the growing demanding needs of users to be connected anywhere and anytime, but also to the possibility of providing a connection in areas beyond reach over wired infrastructure.

There are numerous application scenarios, and others are currently under development, for the situations in which it is essential to have a stable Internet access and high performance even in the conditions of mobility:

- Wi-Fi on public transport.
- Connection between moving units and central station (e.g. Rescue units).

- Video surveillance of means of transport (e.g. Transport values).
- Telemedicine in mobility (e.g. Ambulances for first aid).

In addition, real time services like audio and video transmission (VoIP, audio/video conference, remote video surveillance, etc.) and services that require high Quality of Service (QoS) are currently having an exponential growth of usage.

A possible approach to improve network performance is based on the possibility to use a technique called VPN Bonding capable of aggregating the available Internet access (Ethernet, 3G, 4G, WiFi, etc.) with the ultimate goal to noticeably improve performance in terms of bandwidth, thus reaching ideal broadband speeds equal to the sum of the available bandwidths. In addition obviously obtaining a high fault tolerance in case of inefficiency. This is possible thanks to load balancing mechanism which acts at the level 2 capable of sorting packages on various available connections.

The basic idea involves the use of different mobile operators in order to compensate possible deficiencies of an operator, sorting the load mainly toward the available connections from other operators who at that moment and at that point offer greater performance.

Empirical studies show that in order to obtain an excellent result tending to the ideal solution, namely that of using a bandwidth equal exactly to the sum of the bandwidths offered by each access, it is essential that traffic can be balanced in a manner proportional to the performance offered by each Internet connection.Obviously, if we focus on mobility contexts in which one has to use the cellular network, it must be emphasized that the QoS (Quality of Service) offered by each access is definitely subject to greater variability when compared, for example, to the QoS offered by a classic ADSL. This is because additional factors that can affect the quality of the connection are involved in the Mobile Internet scenario: propagation conditions, interference levels, dependence on activities of other users as a shared communication channel, saturation of the cell to which it is hooked, but especially the concept of mobility, which can lead the user to move from a good coverage area to a poor radio signal coverage areas thus ensuring that the performance of the data connection may be affected.

As mentioned above, in order to cope with the variability of access conditions there should be a real-time evaluation of the QoS offered by each single data access, so as to vary in an adaptive way the weights to be assigned to the load balancing mechanism and thus try to always balance the load in an optimal manner.It is therefore essential to identify the techniques to make an accurate QoS estimation and simultaneously have low times of convergence in highly dynamic environment.

Section 2 outlines the state-of-the-art bandwidth prediction techniques that use a dataset of past collected information, according to a certain point in the territory. Section

3discusses in brief the Smart VPN Bonding technique [1] [2], providing an overview of the techniques so far adopted for the estimate of the QoS, in particular the available bandwidth, highlighting problems and introducing benefits that an approach through a predictive neural network could offer.

2. Related Works

In literature we can find different application contexts in which it is useful to perform certain actions on the basis of predictions based on the analysis of historical events. In particular, this approach is used in many contexts to ensure high QoS for network applications [3] [4].A similar approach could be useful to improve performance in the algorithms used in the handover mechanisms.

In [5] a handover mechanism is proposed using a predictive method based on fuzzy logic, while in [6] a vertical handover algorithm is suggested based on the prediction of RSSI so as to be able to make an intelligent and flexible passage of information through different 4G wireless communication systems, reducing the switching delayin comparison withthe classical algorithms of vertical handover.In [7] and [8] the idea of building the "bandwidth map" is put forward to enhance the QoS in highly mobile environments. Through the use of these maps, based on information collected in the past, one can expect the available bandwidth in a given geographical point, calculated as an average historical value, and as a consequence dynamically determine the most suitable bit rate for encoding video streaming.

In some real applications it is very useful to predict some parameters by alimited data subset. In particular some studies are concerned about the relation between packet delay and other parameters. For instance, in [9] a relation betweenRound Trip Time (RTT) and other geographic and network properties is investigated.Finally, to improve prediction and reduce the error rate different approaches based on the use of Neural Networks have been studied, in particular for the purpose of the Radio Frequency (RF) power prediction [10], [11] and for the bandwidth estimation [12], [13].

3. Smart VPN Bonding

3.1. *Architecture*

As discussed in previous sections, the Smart VPN Bonding technique allows aggregating the resources offered by two or more mobile radio data accesses obtaining a remarkable increase in performance in terms of bandwidth. Fig.1 indicates the proposed architecture of the Smart VPN Bonding[1], [2].

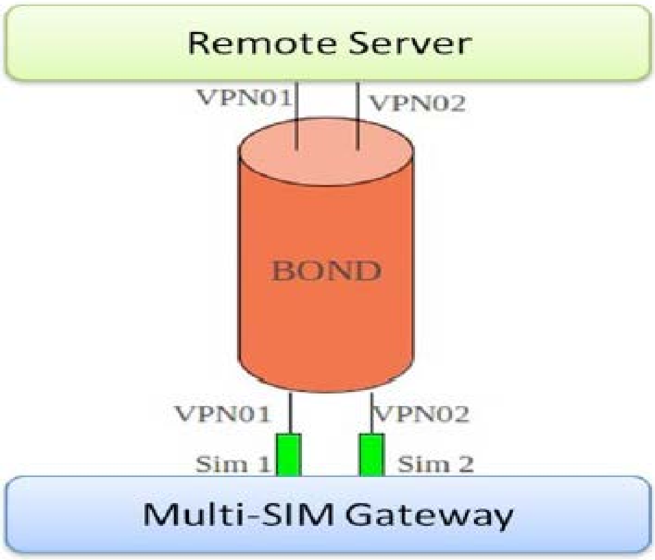

Fig. 1. Smart VPN Bonding.

The scope is to create a VPN tunnel between each access mobile radio and the end point of the communication, i.e. the remote server. After creating the VPN tunnels they can be aggregated into a single interface with the aim to establish a broadband connection between the source and the destination.This is possible since a load balancing mechanism capable of sorting the frames into various VPN tunnels aggregated in the “Bond” interface is adopted. Obviously the performance can be boosted in terms of bandwidth if traffic is balanced in proportion to the available bandwidth provided by each access or more efficient sort [14].

Considering the contexts in mobility, where the QoS is subjected to high variability, it has been necessary to combine this technique with an adaptive load balancing mechanism able to vary dynamically the load in a mannerproportional tothe estimated available bandwidth on each data access. The available bandwidth is an important metric to estimate the QoS provided by a link or end-to-end path. The available bandwidth of a link is the unused link capacity. So the link capacity depends on the transmission technology adopted at thefirst level of TCP/IP protocol stack and propagation medium, the available bandwidth additionally depends on the cross-traffic at that link. In a specific instant in time a link can assume two conditions: is transmitting a packet at a bit rate equal to the full link capacity or is idle. Thus a better definition of available bandwidth takes into account a time averaging of the instantaneous link utilization over a time interval. The average link utilization during a time period τ is given by:

TABLE I
BANDWIDTH MEASUREMENT TOOLS [15]

Tool	Author	Measurement metric	Methodology
Pathchar	Jacobson	Per-hop Capacity	Variable Packet Size
Clink	Downey	Per-hop Capacity	Variable Packet Size
Pchar	Mah	Per-hop Capacity	Variable Packet Size
Bprobe	Carter	End-to-End Capacity	Packet Pairs
Nettimer	Lai	End-to-End Capacity	Packet Pairs
Pathrate	Dovrolis-Prasad	End-to-End Capacity	Packet Pairs & Trains
Sprobe	Saroiu	End-to-End Capacity	Packet Pairs
Cprobe	Carter	End-to-End Available-bw	Packet Trains
Pathload	Jain-Dovrolis	End-to-End Available-bw	Self-Loading Periodic Streams
IGI	Hu	End-to-End Available-bw	Self-Loading Periodic Streams
PathChirp	Ribeiro	End-to-End Available-bw	Self-Loading Packet Chirps
Treno	Mathis	Bulk Transfer Capacity	Emulated TCP throughput
Cap	Allman	Bulk Transfer Capacity	Standardized TCP throughput
Ttcp	Muuss	Achievable TCP throughput	TCP connection
Iperf	NLANR	Achievable TCP throughput	Parallel TCP connections
Netperf	NLANR	Achievable TCP throughput	Parallel TCP connections

$$u_l(t-\tau,t)=\frac{1}{\tau}\int_{t-\tau}^{t}u(x)\,dx \qquad (1)$$

Where $u(x)$ is the instantaneous link utilization at time *x* that can assume a binary value: 0 if the link is idle, 1 if the link is transmitting a packet. Once the average utilization of the link is known the available bandwidth of the link is calculated as follows:

$$A_l=(1-u_l)\,C_l \qquad (2)$$

Where:

- A_l is the link availablebandwidth.
- u_l is the average utilization of the link calculated using equation (1).
- C_l is the link capacity.

The previous definition of link available bandwidth can be extended to a multi-hop path; in this case the end-to-end available bandwidth is determined by the link with the minimum non-used capacity.

$$A=\min_{l=1\ldots N}A_l=\min_{l=1\ldots N}(1-u_l)\,C_l \qquad (3)$$

Where N is the number of hops along the path. According to equation (3) the end-to-end available bandwidth is determined by the link of the path that providesthe minimum available bandwidth, also called *tight link* to avoid confusion with the term *bottleneck link* usually referred to the link with the minimum capacity [15].

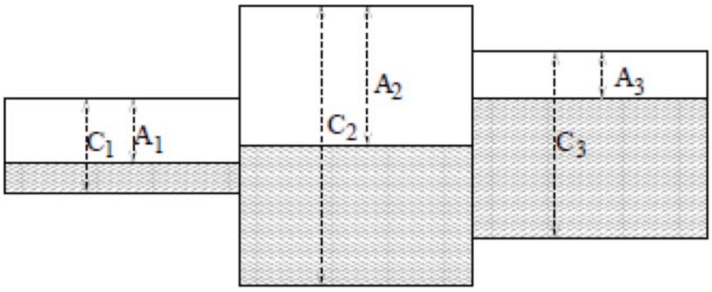

Fig. 2. Pipe model with fluid traffic - 3-hop network path.

So we can define the end-to-end available bandwidth as the maximum rate that the path can provide without reducing the cross-traffic rate [16][17].

A better understanding of end-to-end available bandwidth is shown in Fig. 2 by using a network path representation based on a *pipe model with fluid traffic*, where each link is represented by a pipe. In particular the width of each pipe represents the link capacity, the shaded area represents the amount of cross-traffic over each link and the blank area represents the available bandwidth. The pipe model allows to easily individuate the *bottleneck link* and the *tight link*; in particular the link capacity C_1 represents the *bottleneck link,* while the available bandwidth A_3 represents the *tight link.*

Some public bandwidth estimation tools are shown in Table 1 highlighting tool name, authors, measurement metric and methodology. In particular we have analyzed two of these: Pathload and Pathchirp.

3.2. *Pathload*

Pathload [16] [17] adopts the Self Loading of Periodic Streams (SLoPS) technique: it is based on a periodic transmission of packet streams from the source to the destination and on the consequent measurement of the One Way Delay (OWD), i.e.the time necessary to the packet to travel from the source to the destination.

The time interval between the stream packets decrease until the OWD is almost constant; when the OWD increase it means that the packet stream rate is greater than the available bandwidth. Fig 3 shows the above mentioned behavior.

The available bandwidth estimation is carried out by sending a series of packet streams of K packets, each of which of L bit, during an interval of T seconds, obtaining a transmission rate of KL/T [bit/sec].Each packet of the stream has a timestamp to indicate the time when the packet was created and sent to the receiver node. When the packet

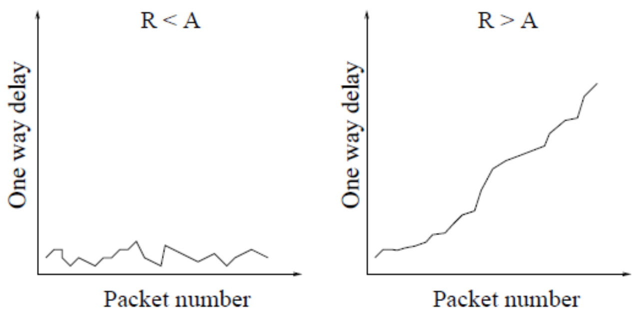

Fig. 3. One Way Delay when Available Bandwidth A is greater than packet stream rate *R* (right) and when *A* is lower then *R*.

arrives to the destination node it compares the arrival time with the timestamp contained in the packet in order to calculate the OWD as follows:

$$OWD_i = a_i - t_i \tag{4}$$

Where:

- $OWD_i$is the One Way Delay relative to the i-th packet of the stream.
- $a_i$is the time arrival of the i-th packet of the stream.
- $t_i$is the timestamp of the i-th packet of the stream.

Equation (4) provide the *relative* OWD because it does not consider the offset due to the non-synchronization between sender and receiver; however, for the Pathload goal, the measurement methodology does not need synchronized clocks, because we are only interested in the relative magnitude of OWDs.The receiver on the basis of the calculated OWDs notifies the sender as follow [18]:

- if $R(i) < A$the sender will increase the next stream rate: $R(i+1) > R(i)$.
- if $R(i) > A$the sender will dcrease the next stream rate: $R(i+1) < R(i)$.

3.3. *Pathchirp*

To estimate the available bandwidth the Pathload employs a long constant bit-rate packet streams by adaptively varying the next packet stream rate in order to converge to the available bandwidth rate [19].

The Pathchirp, instead, employs an exponentially spaced chirp probing train, as shown in Fig. 4.The exponential variable packet rate allows to reduce time necessary to estimate the available bandwidth and the probing packets number.

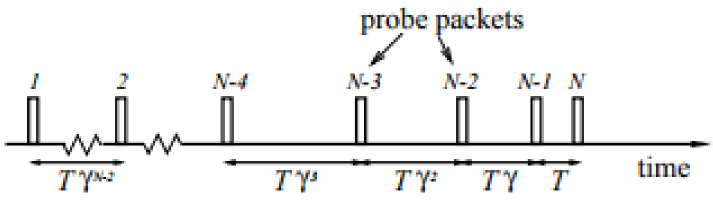

Fig. 4. The pathchirp probing traffic.

The pathchirp estimates the available bandwidth by sending different packet chirps from sender to receiver, each of which composed by N packets, and then carrying out a statistical analysis at the receiver.

The packets are sent using a Variable Bit Rate (VBR) since the next packet interspacing time is defined as function of a spread factor γ_k; the instantaneous rate of i-th packet is:

$$R_i^{(m)} = P/\Delta_k \tag{5}$$

Where:

- $R_i^{(m)}$ is the instantaneous bit rate at packet *i*.
- P is the packet size [bit].
- Δ_k is the *time* space between packet *i* and packet *i+1*.

Similarly to the pathload, the pathchirp analyzes the OWDs: when delay begins to increase means that a node along the path is congested, e.g. the transmission rate is greater than the available bandwidth; then the available bandwidth is estimate as follows:

$$A = R_k \tag{6}$$

Where k is the packet which the OWD begins increasing and R_k is the instantaneous bit rate at the packet k, according to equation (5). In order to provide a good available bandwidth estimation for the specific application scenario a performance comparison between the two analyzed bandwidth measurement techniques in terms of accuracy and convergence time was carried out [3].

The tests were carried out by selecting 20 test points in an urban path; more specifically the first 10 points characterized by a high signal to noise ratio and the second 10 points characterized by low signal-to-noise ratio. In particular the Fig. 5 shows the available bandwidth estimations measured by means of the two analyzed tools and by means of a common file transfer protocol session which was taken as the reference value of real available bandwidth. Unlike Pathchirp and FTP, the pathload estimation does not provide

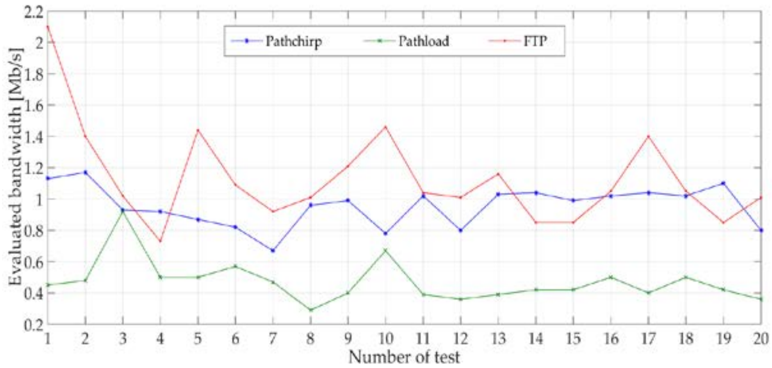

Fig. 5. Bandwidth measurement comparison.

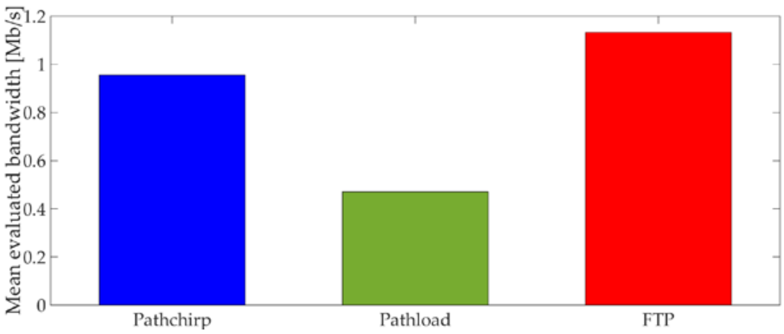

Fig. 6. Average bandwidth measurements.

an exact available bandwidth value, but a range of possible bandwidth values by indicating minimum and maximum estimated bit rate; the pathload bandwidth estimations shown in Fig. 5 is calculated as average value between the minimum and maximum values provided by the tool.Whilein Fig. 6 the average bandwidth measurements carried out by using the three bandwidth estimation approaches are depicted.

The obtained results (see Fig. 5 and Fig. 6) prove that the Pathchirp tool have better performances with respect to the Pathload tool, both in terms of accuracy that in terms convergence time; for this reason has been employed as the available bandwidth measurement tool in the Smart VPN Bonding technique.

3.4. *Performances evaluation*

In order to evaluate the performance of Smart VPN bonding technique we report the results of a test campaign [1], [2].

Fig. 7. The experimental prototype based on ALIX2D2 boardemployed during test campaign [2].

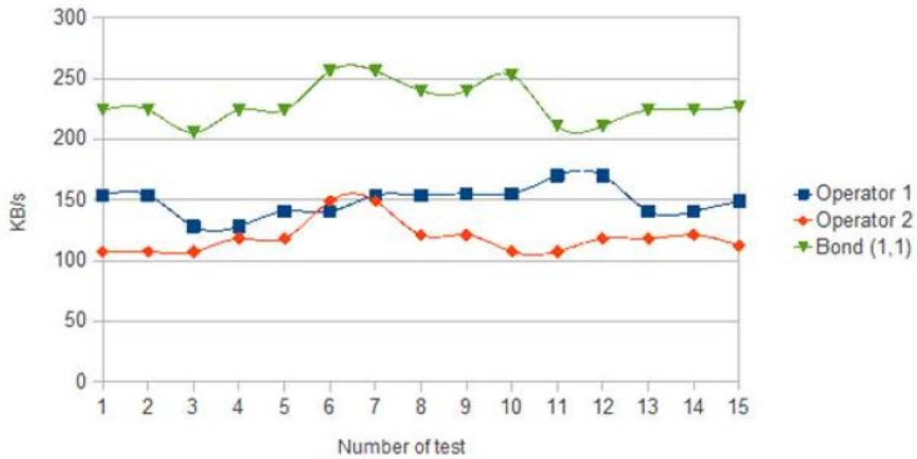

Fig. 8. Thethroughput measured in good network conditions for the Operator 1, Operator 2 and Bonding interface.

The tests were carried out using a prototype based on ALIX2D2 board, a system board optimized for routing and network applications; two USB Internet Keys equipped with two SIMs of different mobile network operators (called Operator 1 and Operator 2) to provide cellular connectivity; ZeroShell and OpenVPN has been used as operative systems and VPN manager respectively; finally a proprietary script has been realized by using *bash* and *python* language to evaluate the end-to-end available bandwidth and, consequently, to establish the weights to assign to load balancing mechanism. The

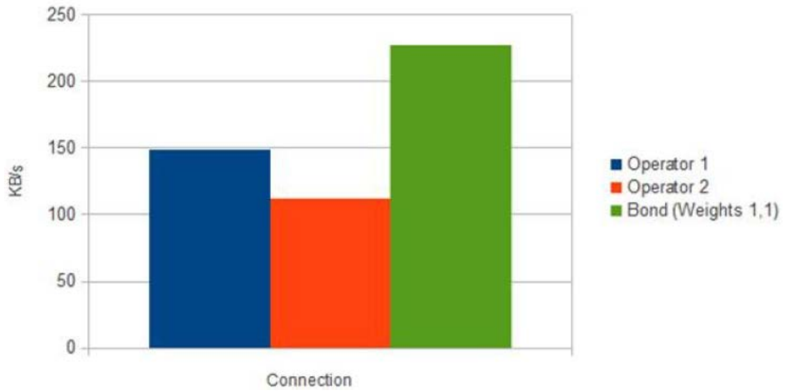

Fig. 9. Average throughputs comparison.

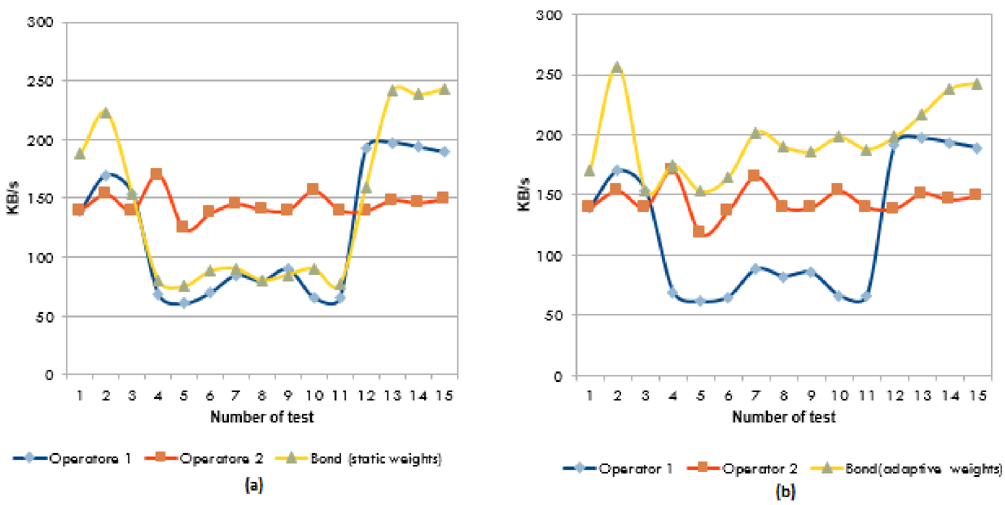

Fig. 10.Operator 1 bandwidth degradation: (a) static weights, (b) adaptive weights.

experimental prototype is shown in Fig. 7, while the Smart VPN Bonding behavior is depictedin Fig. 8.

The performances are obtained in terms of throughput measured using some FTP sessions over the two Internet accesses in 15 different geographic test points. In this scenario the QoS offered by Operator 1 is comparable to Operator 2. The Fig. 9shown the average values obtained.In this case both operators provide ahigh QoS, so a staticapproach based on round robin strategy applied to loadbalancing mechanismrepresents a

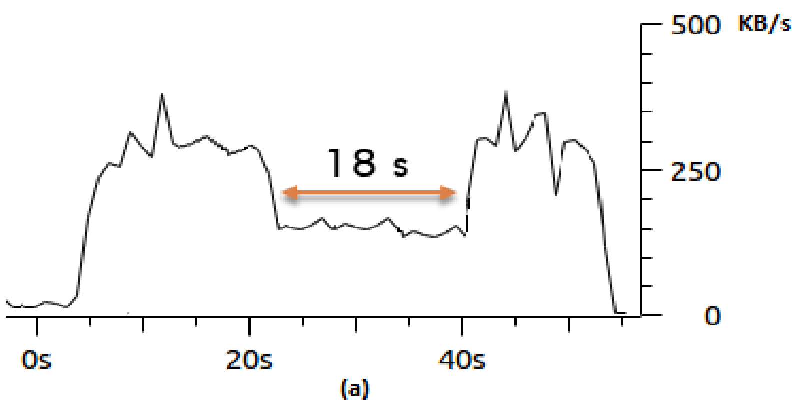

Fig. 11. The Smart VPN Bonding time response.

good solution,increasingperformance by more than 50% if compared to the best mobile operator.

The performance delivered by the VPN bonding coupled with the static load balancing between the two available Internet accesses is satisfactory in the above mentioned scenarios. However, this technique has some disadvantages when the bandwidth offered by two operators is not similar.

Fig. 10 shows a particular case in which the available bandwidth provided by Operator 1 is affected by a considerable degradation due to a poor radio coverage. In this case a static weights assignment to load balancing mechanism don't represent the best approach (Fig. 10a).Indeed, the bonding interface behavior is similar to the worst mobile operator, so the VPN bonding technique does not offer any performance improvement because of the incorrect weights assignment. Instead, using an adaptive weights assignment in order to counteract the drawbacks related to the variability of the end-to-end bandwidth offered by each radio operator along the path the performance in terms of throughput is considerably enhanced (Fig. 10b).

The scenarios above mentioned highlight the advantages and bandwidth improvement provided by Smart VPN Bonding. However, a limit of this technique is represented by high response time to react rapidly to changing network conditions due to bandwidth estimation tool.Fig. 11 shows the performance of Smart VPN Bondingtechnique transmitting alarge file during a change oflocation site, from a good to poor radio coverage areas for one of two mobile operators.

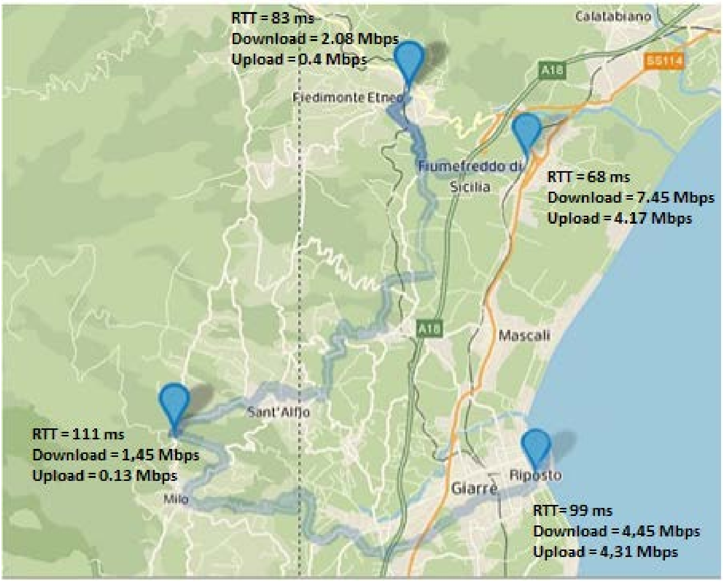

Fig. 12. The Testbed Scenario.

After the change of location site the throughput measured on bonding interface is considerably lower caused by incorrect load balancing. From the example illustrative in Fig. 11, the system has required about 18 seconds to estimate the available bandwidthoffered by both internet accesses, to recognize the changing network conditions and modify the weights assignment to load balancing mechanism. In fact, as soon as the change of weights has occurred, the throughput on bonding interface increases.

This high response time has encouraged the authors to investigate the relation between RTT and available bandwidth in a specific geographic location, in order to obtain an accuratebandwidth estimation in a very short time. Indeed, the RTT measurement is very easy and much faster than available bandwidth estimation, and even more suitable in high mobilitycontext.

In order to verify and analyze this relation a Neural Network approach was adopted. The dataset for the NeuralNetwork training includes values of RTT, download end-to-end available bandwidth and upload end-to-end available bandwidth calculated every 5 minutes. To filter out any episodic RTT effects, each RTT measurement was calculated as the median value of 5 individual samples spaced 2 seconds apart. The available end-to-end bandwidth measurements were carried out using *Pathchirp* tool.

4. The dataset

The dataset for Neural Network training includes the datacollected in an urban scenario, as shown in Fig. 12. Along the path shown in Fig. 12, thetest points have been selected

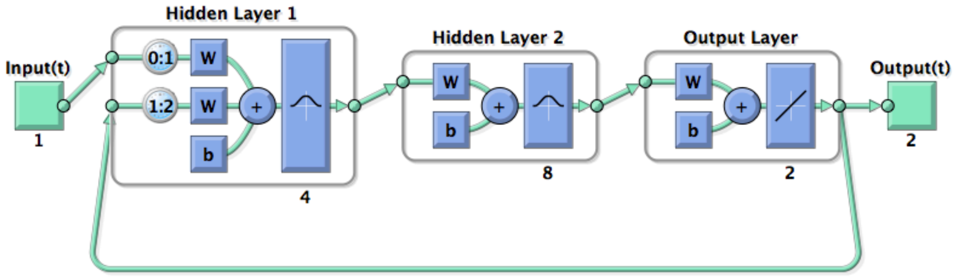

Fig. 13. The RNN used for the prediction of the upload and download rates.

to measure RTT, end-to-end upload and download bandwidth. In Fig. 12 are reported just some examples of measuring points.

As mentioned in Section 3, the end-to-end available bandwidth estimation tools have long convergence time, inadequate for high mobility contexts, so the relationship between available bandwidth values and RTT is analyzed, in order to adopt RTT measurement to predict the available bandwidth values. For each test point, 60 values of RTT, end-to-end upload and download available bandwidth have been collected for the training of the Neural Network. In Section 5 the results and the performance for one test point are reported. These resultscan be extended to other test pointsthanks to the generalizationability of the Neural Network.

5. The neural predictor

Different topologies of Neural Network were experimented inorder to gain some insight into the most appropriate network architecture [20], [21], [22], [23].

The best conducted experiments in terms of MSE, no-overfitting and generalization were obtained using a real-time Recurrent Neural Network (RNN) as depicted in Fig. 13.The RNN is composed by an input layer, an output layer and two hidden layers: the four neurons of the first hidden layer and the eight neurons of the second hidden layer have radial basis transfer function. While for the two neuronsof the output layer has been used a linear transfer function.The RTT time series is used as input vector while the upload and download rate time series are used as output vectors. The input vector is delayed with zero step delay and one step delay while the output vectors are delayed with one step delay and two step delay. So the RNN predicts the values of upload and download rates at time t_0+1based on the value of the RTT at time $t_0$and t_0-*1*. The time step in this paper is one minute. The learningcurves, shown in Fig. 14, pointed out the good performance of the RNN reached after 100000 epochs with a mean squared error of 6.6e-05 and an

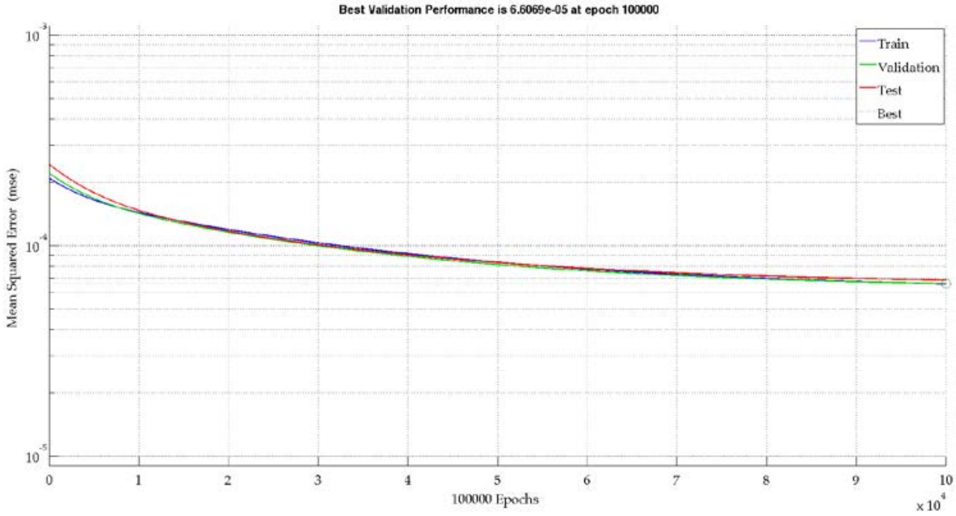

Fig. 14. Learning curves of the Recurrent Neural Network.

excellent generalization due to the fact that the test curve is always very close to the training curve.

6. Conclusion

Today many applications require a high Quality of Service (QoS) to the network, especially for real time applications like VoIP services, video/audio conferences, video surveillance, high definition video transmission, etc. Besides, there are many application scenarios for which it is essential to guarantee high QoS in high speed mobility context using an Internet Mobile access.

In this paper we propose a Neural Network-based approach to Smart VPN Bonding, technique allowing to aggregate the resources offered by two or more mobile radio data accesses obtaining a remarkable increase in performance in terms of bandwidth.More specifically, in this paper we have investigated the relation between the Round Trip Time (RTT) and the end-to-end available bandwidth (upload and download) in order to simplify and speed up the estimation bandwidth process.

The results highlight that it is possible to estimate the available bandwidth based on the knowledge of the past values of the RTT obtaining a low MSE. Thanks to this information it is possible to apply a fast reconfiguration of weights of the load balancing mechanism adopted in VPN bonding technique to guarantee a higher end-to-end available bandwidth than a static approach (e.g. round robin strategy). This approach is very useful to improve the VPN bonding performance, but can be used in several other application scenarios for the important adaptation of available bandwidth (e.g. video transmission frame rate).

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