Performance Improvement of Wireless Link Reliability in The Context of Cognitive Radio

Badr Benmammar, Asma Amraoui and Wassila Baghli
Laboratory of Telecommunication of Tlemcen
UABT - Tlemcen, Algeria

Summary
Cognitive radio is a software radio whose control processes leverage situational knowledge and intelligent processing to work towards achieving some goal related to the needs of the user, application, and/or network. Cognitive radio is born of the need to introduce intelligence and flexibility in managing spectrum resources that become increasingly valuable with the rapid proliferation of standards and radio services. In this paper, we propose a new approach which uses the cognitive radio for improving wireless link reliability. We show through experimentation the interest of our approach.

Key words:
Cognitive radio, mobility, handover, link reliability, machine learning.

1. Introduction

Cognitive radio CR will lead to a revolution in wireless communication with significant impacts on technology as well as regulation of spectrum usage to overcome existing barriers. CR, including Sofware Defined Radio SDR as enabling technology, is suggested for the first time in [1] and [12] to realize a flexible and efficient usage of spectrum.

Applications in the context of CR are often included in its definition because of the compelling and unique applications afforded by CR. Additionally, there are many existing software radio techniques that CR is expected to enhance. The following are frequently advocated applications of cognitive radio [2]:

- Improving spectrum utilization and efficiency.
- Improving link reliability.
- Advanced network topologies.
- Automated radio resources management.

Most researches on CR networks have focused on the exploitation of unused spectrum. However, the CR nodes possess the necessary qualities to make a considerable progress in the reliability of wireless networks [2], which has been less explored, so that is why we were interested by improving wireless link reliability in the context of CR.

Connecting mobile users generally consists of a series of fixed and mobile networks. Any consideration of reliability must take into account the end to end network connection. These ideas have been important areas of research in wireline networks [3] and in infrastructure wireless networks [4] [5]. However, the end to end reliability is limited by its weakest components. Traditionally, the wireless link access is seen as the weakest link, and many techniques such as channel coding and diversity have been proposed to the physical layer to improve the quality of radio link [6].

The aim of our paper is to propose a technique to improve wireless link reliability using the CR. For this, it seemed appropriate to choose a CR application and imagine the scenario on which we will apply our approach. Our technique is based on machine learning.

In this paper, we first present a state of the art of traditional reliability in wireline networks. Then, we present the cognition cycle changed to management failures for a wireless link in a CR. Finally, we describe the scenarios proposed and the results of our experimentation.

2. Traditional reliability in wireline networks

Network robustness has been a major driving factor in the design of wireline networks partly due to regulatory requirements and customer expectations. Network robustness implies network reliability, which generally in a communication network is related to the ability to [5] :

- Prevent the occurrence of failures.
- Solve and recover from failures.

2.1 Prevention mechanisms

Networks use prevention mechanisms to decrease the occurrence or the severity of failures. Most of these approaches are based on the use of dependable hardware and software for the transmission links and nodes. Other solutions such as selecting less-hazardous environments and equipping communication cables with protective covers are also classified as prevention methods.

The objective of a prevention mechanism is to postpone the occurrence of failures. The most appropriate

---

Manuscript received January 5, 2012
Manuscript revised January 20, 2012

performance metrics to evaluate a prevention mechanism are thus the number of failure occurrences in a period (Failure Rate), the probability of a failure occurrence (Reliability) and the duration between two consecutive failures known (Mean Time Between Failures) [7].

2.2 Recovery mechanisms

Recovery mechanisms are divided in Protection and restoration methods. Protection mechanisms are network design and capacity allocation techniques [5] which assign backup resources in advance, whereas restoration methods attempt to find a solution after the occurrence of a failure. Usually, recovery mechanisms are hybrid and use a mixture of the two approaches.

2.2.1 Protection methods

In general, protection methods specify some reserved (spare, backup) resources that will be used when a failure happens. The resource substitution can be done automatically by the network or manually by a network administrator.

2.2.2 Restoration methods

In restoration methods, when a resource fails, there is no pre-assigned backup resource and the substitute resources should be found dynamically.

3. Cognitive radio networks and wireless link reliability

In this context, the main objective is to design a wireless system architecture that can counter wireless failures and improve wireless network reliability using approaches similar to those currently in place in wireline networks. Considering its cognitive features and intelligence, the CR has the necessary attributes to achieve this objective. The modified CR cognitive cycle presented in Figure 1 illustrates the inherent capability of CR nodes (CRN) to prevent or recover from failures to improve wireless network reliability.

Stages 1 and 2 consist on the environment observation and the monitoring of the performance and QoS parameters. In stage 3, the cognitive radio detects whether any new event has occurred or may be occurring in the near future. To make the most appropriate decision, the CR node classifies the new event as a Warning or Failure in stage 4. In the former case, the CR deploys failure prevention measures. For example, if a CR mobile station detects that its distance from the base station is increasing, it can switch to a lower modulation and coding to prevent path loss failure. In the later case, the CR node characterizes the failure according to the failure classification chart and uses the appropriate protection and restoration techniques (stages 5 and 6). The CR node can also learn from the current experiences and observations to help it in the development of more efficient plans in the future (stage 7) [7].

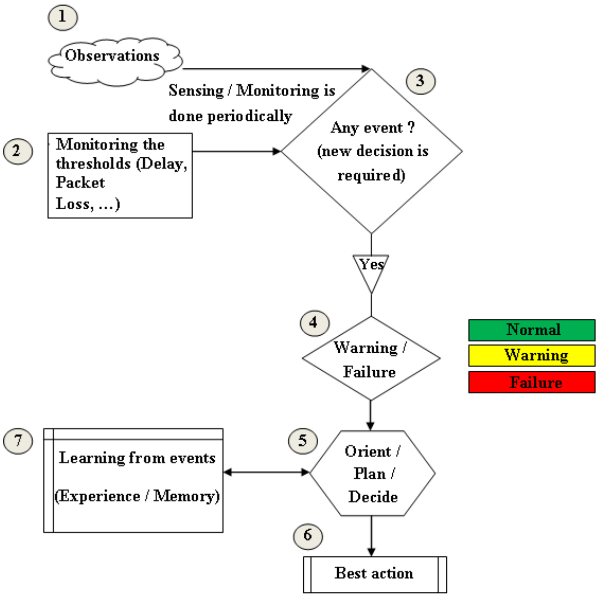


Fig. 1 Modified cognitive cycle for failure management [7]

3.1 Prevention mechanisms

Transmission techniques with higher level of reliability can be employed in CRNs to reduce the probability of link failure (failure rate) or its severity. For example, wideband transmission techniques, such as spread spectrum, frequency hopping and OFDMA can be used to increase the wireless network reliability in environments with high levels of interference. Using the reconfigurability and reasoning of CR nodes, when a CRN detects an environment with high level of interference or a primary network using wideband technologies, after the required coordination, it can reconfigure the physical layer to a more appropriate wideband technology. Similarly, transmission parameters such as the channel coding type and rate, the signaling rate and the modulation can be adjusted to increase the reliability of distant users operating with a higher noise level, or to mitigate the impact of interference.

3.2 Sensing mechanisms

An important feature of cognitive radios is their ability to perform spectrum sensing. A reliable operating frequency channel can therefore be selected based on its interference level (from primary or secondary users) and its attenuation, shadowing and fading characteristics. Increasing the accuracy of the sensing algorithms is thus a primary factor in providing an accurate channel characterization and in improving network reliability. Better sensing algorithms and longer sensing periods can be used to improve the accuracy.

3.3 Historical and defined data

The CRN can use its learning capabilities to register several events. For example, Geographical and environmental information can be obtained through a GPS in the CRN. When the CRN is approaching these geographical coordinations, a warning alarm is generated that notifies the CR to take adequate measures to prevent the occurrence of failures.

4. Scenarios and proposed solutions

4.1 Scenario

The Figure 2 below shows a path followed by a mobile subscriber when it switches to an area where the signal quality drops to an unacceptable level (shown in red) due to a gap in coverage, we assume that the client uses video conferencing over the route.

Fig. 2 Signal quality associated to a cognitive radio

4.2 Proposed Solution

After several incidents, the CR should be aware of the problem. Then, through some geolocations or the ability to learn the time of the day when this happens, the radio can anticipate the difference in coverage and know the necessary signal to the base station to change characteristics of the signals when the user approaches the deficient coverage.

4.3 Quality of service in video conferencing

With the emergence of new services such as video conferencing and video streaming, the need to treat the frames one by one and to know how differentiate services becomes primordial.

In the literature, we found that to have a good QoS in video conferencing, it is necessary that:

- **Throughput** must be > **384 Kb/s**.
- **Delay** must be **< 200 ms**.
- **Jitter** must be **< 30 ms**.
- **Packet loss** must be **< 1%**.

However, as we don’t have real data used in the CR and it is the case of the whole community, we had to play the role of the expert to assign the needed data for our simulation.

4.4 Application

As mentioned above, we will use video conferencing in the case of a mobile user who needs to take a path where the signal quality drops to an unacceptable level due to a gap in coverage, giving a very low QoS. This can be remedied by using the CR, but problematic arises: ***WHEN*** and ***WHY*** to use cognitive radio?
Most research related to the QoS of video conferencing, take into account throughput as pertinent parameter. For this reason, we choose the “**Throughput”** as a single pertinent parameter for our application. For this, a throughput classification is required, and as we play the role of the expert, we have created our own database following certain rules in order to apply our approach. The database was divided into two parts, the first one for learning and the second one for testing. The value of the throughput will change almost every time it is measured during the day even on the same route, for this reason, our measures have been taken into account for 5 weeks at 3 different intervals of the day (8am – 11am, 11am – 3pm, 3pm – 5pm) excluding weekend.
We proposed to affect throughput on three classes:

- **Gold** for samples where the throughput is greater than **384 Kb/s**, ensuring 100% quality satisfaction of the user.
- **Silver** for samples where the throughput is between **160 Kb/s** and **384 Kb/s**, of acceptable quality.
- **Bronze** for samples where the throughput is less than **160Kb/s**. This means that video conferencing is not satisfactory, and it is the class that interests us because this is when we use the CR.

Fig. 3 Database classes

4.4.1 *First question "WHEN"?*

For the data classification, we used three different algorithms derived from the field of machine learning.

- The k-nearest neighbors algorithm (K-NN) which is a supervised classification algorithm, we have programmed it in the java environment.
- The multilayer perceptron algorithm (neural networks), in weka (Waikato Environment Knowledge Analysis). [**Appendix A]**
- The C4.5 algorithm of decision trees, in weka. [**Appendix B]**

Among those, the K-NN algorithm was tested with several values of K on the test database and each time the result was different, but it is satisfactory until the value of K=6. We chose this algorithm, considering which it gave better results (compared to the other algorithms), shown below:

Table 1. Classification obtained with the K-NN algorithm

Values of K	Instances correctly classified		Misclassified instances	
K=1	20	100%	0	0%
K=2	18	90%	2	10%
K=3	18	90%	2	10%
K=4	18	90%	2	10%
K=5	18	90%	2	10%
K=6	18	90%	2	10%

In the weka environment, K-NN algorithm, called IBK gave the following results:

Table 2. Classification obtained with Weka

Values of K	Instances correctly classified		Misclassified instances	
K=1	20	100%	0	0%
K=2	19	95%	1	5%
K=3	19	95%	1	5%
K=4	18	90%	2	10%
K=5	18	90%	2	10%
K=6	18	90%	2	10%

For K=1: All the throughput examples were well posted in their appropriate class, as shown in the confusion matrix and the graph below:

$$\begin{array}{ccccl} a & b & c & & \\ 2 & 0 & 0 & a & \text{Gold} \\ 0 & 10 & 0 & b & \text{Silver} \\ 0 & 0 & 8 & c & \text{Bronze} \end{array}$$

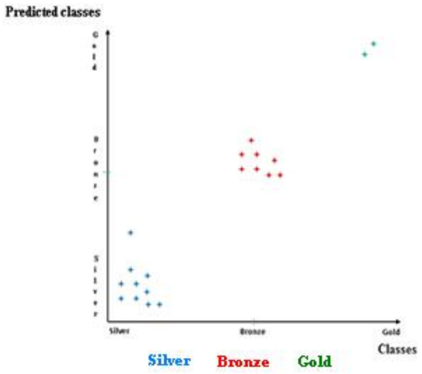


Fig. 4 Results and confusion matrix of the classification with K=1

Whereas, with K=**2**, one sample was misclassified, we notice that in the confusion matrix and the graph.

$$\begin{array}{ccccl} a & b & c & & \\ 2 & 0 & 0 & a & \text{Gold} \\ 0 & 10 & 0 & b & \text{Silver} \\ 0 & 1 & 7 & c & \text{Bronze} \end{array}$$

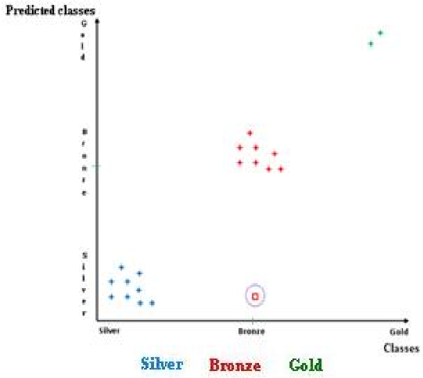
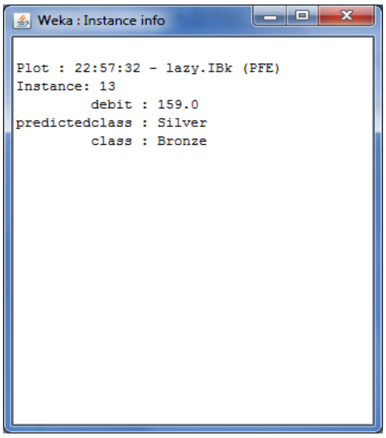


Fig 5 Results and confusion matrix with k=2

Note: items close to the threshold of a class are misclassified. For example, the instance which have a throughput of 159Kb/s was ranked on Silver class instate of the Bronze one, for the other values of K, the result is more divergent.



```
Plot : 22:57:32 - lazy.IBk (PFE)
Instance: 13
        debit : 159.0
predictedclass : Silver
        class : Bronze
```

Fig. 6 Instance misclassified with Weka

Report: according to the results of the classification, the cognitive radio will be activated each first day of week from 8am to 11am and from 3pm to 5pm, and every Wednesday from 8am to 5pm because in these intervals the throughput belongs to the Bronze class <160Kb/s. So, through this, the question *When* is answered.

For more general rules, it would be interesting to consider the other QoS video conferencing parameters and classify these data using other methods of artificial intelligence such as fuzzy logic and genetic algorithms.

4.4.2 Second question “WHY”?

Now, We will justify the usefulness of the CR, this by supposing that the spectrum sensing is already done by the receiver of our mobile terminal which is in this case a multimode wireless communication terminal (MWCT), so capable to support multiple access technologies such as GSM, UMTS or WiMAX.

Considering that, the spectrum is not used at 100%, we can represent the frequency bands into two sets: the first contains the occupied bands and the second contains the free ones.

The mobile terminal must switch to an unused frequency band among those available in the free bands set.

For our approach, scenarios were studied to show the usefulness of the CR, this based on the number of free bands and the time of use of each one, we identified three possible scenarios:

- **Favorable (best case):** the receiver detects a free band and uses it during all the way without any interruption caused by the primary user.
- **Unfavorable (worst case):** the receiver does not detect any free band (empty set) or it detects some bands but their use interferes with the primary users. In this case the CR is not used because the secondary user should not disturb the primary users.
- **Common (N frequency with N hops):** the terminal uses a free band b1, then there is an interruption caused by the primary user, so it switches to another free band b2 (he made a hop). If the primary user of b2 needs his band, the secondary user must switch again, and so on, until the end of the condition when he opts for the CR (before returning to his initial frequency band), he will have done N hops.

For our application, we have based on the number of hops done by the CR during all the way of the secondary user. In each of the scenarios mentioned above we calculated the time of interruption which is the required time for the terminal to access a free band and use it.

The time of interruption will be defined as follows: **T.interruption = (T.sensing + T. establishment) x number of hops.**

The sensing time is the required time to detect a free band, it is negligible compared to the time of establishment, it is even included in the time of establishment for some algorithms which treat the diagonal handover (switching between wireless networks which uses the subjacent technologies such as the standard IEEE 802) or the vertical handover (switching from one access technology to another).

In the literature, we found that the time of establishment necessary to exploit a free frequency band of another technology is 5 seconds on average [8] and [9].

T.sensing <<T.establishment, which gives us:
T.interruption = T. establishment x number of hops.
We call time of rupture: the necessary time to return to the initial frequency band. So, it is the sum of the time of interruption and the time of use of each band, knowing that, the time of use can differ from a band to another according to the primary user.
T.rupture = T.interruption + T.use

4.4.3 Experimentation results

To support our proposal and to better understand, we compared the QoS with and without cognitive radio (case without CR means that our terminal has only one access technology and works on the same frequency band). The graphs below illustrate this comparison. For being readable, we supposed that the maximum time of rupture is 5 min and that the free band set contains 7 bands.

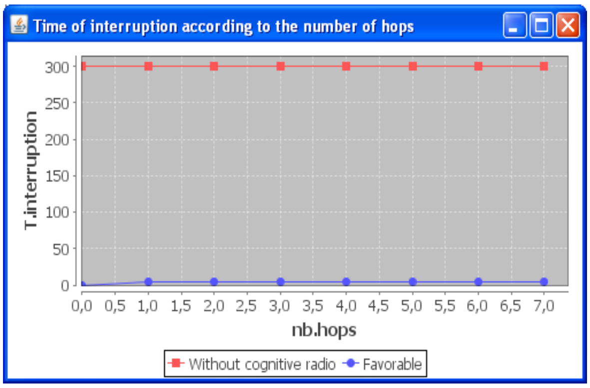


Fig 7 Comparison between the favorable scenario and the case without cognitive radio

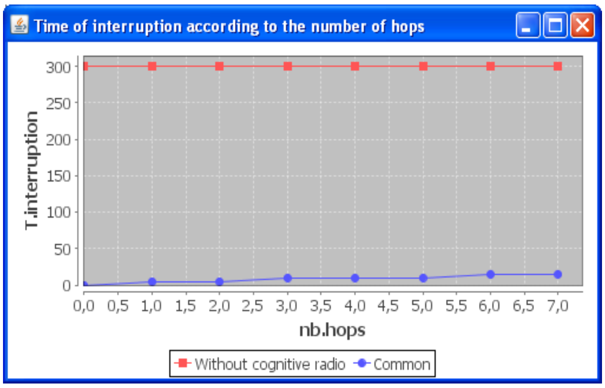


Fig. 8 Comparison between the common scenario and the case without cognitive radio

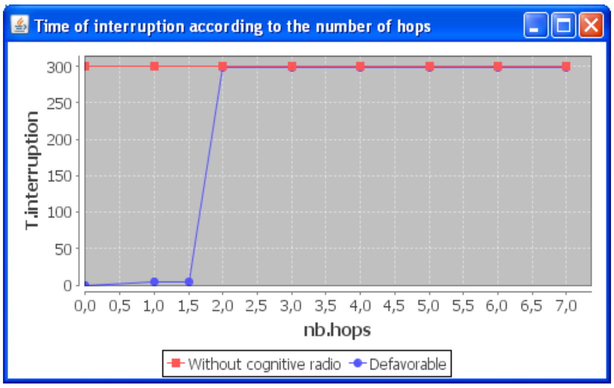


Fig. 9 Comparison between the defavorable scenario and the case without cognitive radio

4.4.4 Results interpretation

Modeled graphs above represent the downtime depending on the number of hops performed. We note that whatever the number of hops, the case with the CR is much better than that without CR.
According to the first graph, of course we lost 5 seconds to connect to the new band but we see that the CR has saved us 295s which is the time without interruption.

For the second graph, we performed three hops, which means that the downtime is 5s x 3 hops: 15s. Despite this, the case with CR is always better.

On the third graph, a single hop was made but the connection was interrupted by the primary user at the beginning, so we took advantage of the CR for a few seconds.

Result : whatever the number of hops performed, the use of cognitive radio is always more efficient.

4.4.5 Summary chart

In summary, the steps taken to achieve the final result are described one by one below:

We specified two aims of using CR when the throughput is in Bronze class and then to prove the importance of its use. Next, we chose to apply our approach to video conferencing.
Then comes the stage of collecting information that identifies the data sources available, but as we don’t have real data, we played the role of the expert to assign measures and label them.

After that, a model of the problem has become. For this we used machine learning techniques such as the k nearest neighbor algorithm, the multilayer perceptron and the C4.5 algorithm. Following the results we have used rules like: **if ‘‘Friday’’ and ‘‘ 8am-11am ’’ then ‘‘ use cognitive radio ’’.**

5. Conclusion

In this paper we extend our previous works on improving video conferencing application quality for a mobile terminal through cognitive radio [13] and [14].

In this work, our expert role has allowed us to choose the throughput parameter to perform a classification that allows the terminal used to gain experience for future events that means that it will know when and where it will activate the cognitive radio.

In our future work, we will seek to reduce the impact of mobility on cognitive radio communications by building predictive models of mobility by referring to previous work such as [10], [11] and [15].

References

[1] J. Mitola, III and G. Q. Maguire, Jr., "Cognitive Radio: Making Software Radios More Personal," IEEE Personal Communications Magazine, vol. 6, no. 4, pp. 13-18, August 1999.

[2] J. Neel, “Analysis and Design of Cognitive Radio Networks and Distributed Radio Resource Management Algorithms”, Faculty of the Virginia Polytechnic Institute and State University, September 2006.

[3] J-P. Vasseur, M. Pickavet and P. Demeester, “Network Recovery: Protection and Restoration of Optical”, SONET-SDH, IP, and MPLS, Elsevier, Ed. Morgan Kauffman, 2004.

[4] A. P. Snow, U. Varshney and A. D. Malloy, “Reliability and survivability of wireless and mobile networks,” Computer, vol. 33, no. 7, Jul. 2000.

[5] D. Tipper, T. Dahlberg, H. Shin and C. Charnsripinyo, “Providing fault tolerance in wireless access networks,” IEEE Commun. Mag., vol. 40, no. 1, Jan. 2002.

[6] D. Tse and P. Viswanath, “Fundamentals of Wireless Communications”. Cambridge University Press, 2005.

[7] A. Azarfar, J-F Frigon and B. Sanso, “Improving the Reliability of Wireless Networks Using Cognitive Radios”. Mars 2011.

[8] S. Busanelli, M. Martalõ, G. Ferrari and G. Spigoni, “Vertical Handover between WiFi and UMTS Networks: Experimental Performance Analysis”, International Journal of Energy, Information and Communications Vol. 2, Issue 1, February 2011.

[9] Z. Daia, R. Fracchiaa, J. Gosteaub, P. Pellatia and G. Viviera, “Vertical handover criteria and algorithm in IEEE 802.11 and 802.16 hybrid networks”, Laboratoire de Motorola Paris.

[10] N. Samaan, B. Benmammar, F. Krief and A. Karmouch. "Prediction-based Advanced Resource Reservation in a Mobile Environment". 18th IEEE Annual Canadian Conference on Electrical and Computer Engineering, CCECE05, May 1-4, 2005, Saskatoon Inn, Saskatoon, Saskatchewan Canada.

[11] B. Benmammar, Z. Jrad and F. Krief. "QoS management in mobile IP networks using a terminal assistant". Wiley/ACM International Journal of Network Management, Wiley InterScience Edition, ISSN (printed): 1055-7148, ISSN (electronic): 1099-1190, Volume 19, Issue 1, Date: January/February 2009, Pages: 1-24.

[12] J. I. Mitola, "Cognitive Radio for Flexible Mobile Multimedia Communications," in Proc. of IEEE International Workshop on Mobile Multimedia Communications, MoMuC '99, San Diego CA, USA, 15-17 November 1999.

[13] A. Amraoui, W. Baghli and B. Benmammar, "Improving video conferencing application quality for a mobile terminal through cognitive radio", 14th IEEE International Conference on Communication Technology (ICCT 2012). Chengdu, China, November 9th-11th, 2012. to appear.

[14] A. Amraoui, W. Baghli et B. Benmammar, "Amélioration de la fiabilité du lien sans fil pour un terminal radio cognitive mobile". Dans les actes du 12 ème Journées Doctorales en Informatique et Réseau (JDIR'11). Belfort, France, 23-25 Novembre 2011. Pages : 1-6.

[15] B. Benmammar and F. Krief. "MQoS NSLP: a mobility profile management based approach for advance resource reservation in a mobile environment". Proceedings of the 7th IFIP IEEE International Conference on Mobile and Wireless Communications Networks (MWCN 2005). Marrakech, Morocco. September 19-21, 2005.

Badr Benmammar received the B.Sc. in Computer Engineering, with high honors, from the USTO (Université des Sciences et de la Technologie Oran), Algeria, in 1999. He received the M.Sc. in Computer Science from Paris 13 University, France, in 2002. He received the Ph.D degrees in Computer Science from the Bordeaux 1 University, France, in 2006. Badr Benmammar was associate professor from 2010 at UABT (Université Abou Bekr Belkaïd Tlemcen), Algeria and research fellow at CNRS LaBRI Laboratory of the University of Bordeaux 1 until 2007. He is performing his research activities in Laboratory of Telecommunication of Tlemcen, UABT, Algeria. His main research activities concern cognitive radio network, quality of service on mobile and wireless networks, end-to-end signaling protocols and Agent technology. His work on quality of service has led to many publications in journals and conferences (Annals of telecommunications, International Journal of Network Management, WiMob, NetCon, ICT, MWCN, ICTSM …).

Asma Amraoui, born in 1989. Graduate of BS in Computer Science in 2009 from the UABT (Université Abou Bekr Belkaïd Tlemcen) in Algeria. Obtained the Master degree in Computer Science option “Intelligent Models and Decisions” in 2011. Currently she is a PhD candidate; she is preparing a doctoral thesis on a topic of research that explores the use of artificial intelligence techniques in the cognitive radio networks. She is attached to the LTT laboratory (Laboratory of Telecommunications of Tlemcen) in Algeria.

Wassila Baghli, received the BS in Computer Science in 2009 from the UABT (University Abou Berk Belkaïd Tlemcen) in Algeria. She obtained the Master diploma in Computer Science option “Intelligent Models and Decisions” from UABT, Algeria, in 2011.

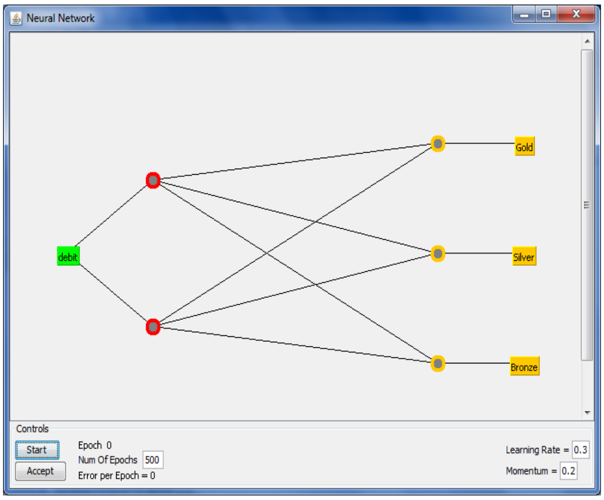
Appendix A

For the classification using the multi layer perceptron algorithm of neural networks, we obtained the following results using weka:

Table A1. Results obtained with the multilayer perception algorithm

hidden layers	**Learning rate**	**Epochs**	**Instances correctly classified**		**Misclassified instances**	
A	0.3	500	59	98,33%	1	1,66%
A	0.5	500	57	95%	3	5%
1	0.3	500	51	85%	9	15%
1	0.3	1000	50	83,33%	10	16,66%
1	0.5	1000	50	83,33%	10	16,66%
2	0.3	500	59	98,33%	1	1,66%
2	0.3	1000	58	96,66%	2	3,33%
2	0.5	1000	59	98,33%	1	1,66%

The figure below shows a neural network containing two hidden layers, a learning rate of 0.3 and 500 epochs.



Epoch 0
Num Of Epochs 500
Error per Epoch = 0
Learning Rate = 0.3
Momentum = 0.2

Fig. A1 Multilayer perceptron

With Matlab, we obtained a classification of only 84% with three hidden layers, a learning rate of 0.2 and 300 epochs :

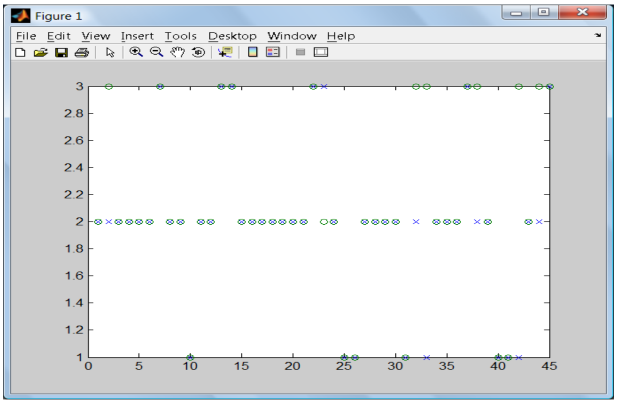


Fig. A2 Classification with Matlab

Remark:

The multi layer perceptron has not given satisfactory results, however we did not get 100%, despite the change of parameters such as the number of hidden layers,the number of epochs and the learning rate.

Appendix B

For classification using decision trees, we chose the J.48 algorithm of weka which is equivalent to C4.5, it correctly classified all instances. The results are:

- Instances correctly classified 60 : 100%.
- Misclassified instances 0 : 0 %.

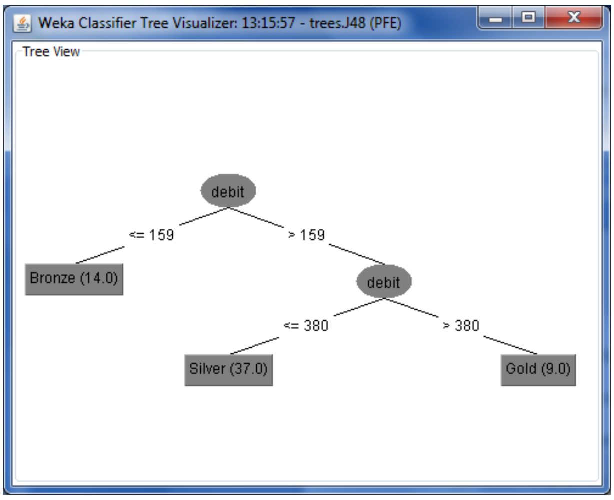


Fig. B1 Decision tree

Remark:

Although the results are satisfactory, the decision tree generated is not exactly what we want because for him the GOLD class starts from a rate of 380 Kb/s instead of 384 Kb/s, this can generate after mistakes with misclassifying some instances.