The Impact Of Extra Traffic On The Control Channel Over The Performance Of CCA Applications

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***Abstract*— This paper presents an analysis of the impact of competing traffic on the control channel on the performance of applications like Chain Collision Avoidance (CCA). These vehicular network's applications are addressed to traffic safety aiming chain collision avoidance. This work shows the impact of signaling messages of other applications (in the control channel) in the CCA application's performance. The results were carried out considering since an ideal scenario (without concurrent traffic) until a scenario with high utilization level of control channel. Besides, the impact of the transmission power in the CCA applications is also evaluated.**

Keywords-vehicular; network; CCA; safety; traffic.

I. INTRODUCTION

With growing number of automobiles traveling through the roads, the probability of accidents increases. Such accidents endanger drivers and passengers, while still causing financial loses.

There are studies being conducted with the purpose of developing new mechanisms to reduce traffic accidents. Among these mechanisms lies the development of Intelligent Transportation System (ITS). Vehicular Ad Hoc Networks (VANETs) are networks formed by automobiles and/or fixed equipments usually localized at the side of the roads. These networks support the ITS through the communication between vehicles and operate to avoid accidents [1] [8]. One of the main motivators for the development of vehicular networks is the development of applications that aim to increase traffic safety [1]. One problem often found in traffic is chain collision. In this case, the braking of one vehicle could lead to collisions among the vehicles that come behind the first one. VANETs are able to support applications with the purpose to avoid chain collisions, they are called Chain Collision Avoidance (CCA) applications [7].

This paper presents a study on the extra traffic impact over the control channel on the performance of manual and automatic CCA applications. The CCA applications are evaluated on 4 scenarios with different levels of traffic competition on the control channel. Their performance is analyzed in terms of vehicle collisions and percentage of successful delivery of emergency messages.

This paper is organized as follows: Section 2 presents the fundamentals of vehicular networks and the Wireless Access in Vehicular Environments (WAVE) architecture. Section 3 describes the related work and contributions of this article. Section 4 presents the problem of chain collisions and the CCA applications. Finally, in sections 5 and 6 are the results and conclusions, respectively.

II. VANETS AND THE WAVE ARCHITECTURE

The primary goal of vehicular networks is to establish the conditions to allow for communication between vehicles. Vehicles can communicate directly (Vehicle to Vehicle Communication – V2V) or by making use of an infra-structure located at the side of the road (vehicle to roadside infrastructure – V2R) [5].

The applications for VANETs can be classified into: i) entertainment applications, ii) driver assistance applications, and iii) traffic safety applications.

The entertainment applications include file sharing, text messaging and Internet access. The driver assistance applications can, for example, provide information about the traffic in a particular region, on the existence of free parking, tourist spots etc. The traffic safety applications aim to prevent accidents. In this class are the applications that warn about the possibility of collisions at intersections, warn the driver about speeding and, in general, anticipate the reaction of the driver in order to decrease the risk of traffic accidents [1].

VANETs have some peculiarities in relation to traditional mobile networks, such as: nodes moving at high speed, short contact time, highly dynamic network, the fact that nodes have their movement restricted by roads, the need to provide high scalability, among others. Those characteristics make the existing protocols for mobile networks not suitable for use in a vehicular environment [2].

An architecture called Wireless Access in the Vehicular Environment (WAVE) is being developed to support vehicular networks [8]. In the experiments performed for this paper, we used the WAVE architecture implemented in the NCTUns 6.0 simulator, including the medium access protocol IEEE 802.11p based on the IEEE 802.11 but modified to work on multiple channels [3].

The WAVE architecture works with multiple channels, a control channel (Control Channel - CCH) and several service channels (Channels Service - SCHS). The control channel can be used to send frames containing Wave Short

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Message (WSM) packets, sent by critical applications. Service channels can be used to send both frames with WSMs and frames containing IPv6 packets [8].

The Wave Basic Service Set (WBSS) is a set of WAVE stations that can communicate using service channels. To join a WBSS a node must first receive a beacon frame that is sent through the control channel. This frame is sent by the WBSS provider node and contains all information necessary for the association of the receiving node. In this paper, WBSS provider nodes were used to transmit beacon frames generating extra traffic on the control channel.

III. Related Work and Contributions

The development of vehicular networks has been widely promoted in order to permit the use of applications to enhance traffic safety [4], [5], [7], [6] and [9]. Among these there are the CCA applications that aim avoid chain collisions through the exchange of emergency messages aimed at preventing sequential collisions of vehicles [7], [9].

Tomas-Gabarron et al. [7] made an evaluation of CCA applications using the IEEE 802.11p, varying parameters such as the power of the signal transmission and the vehicle speed (alternating between 108 km/h and 144 km/h). The authors evaluated the performance of the CCA application in cases where only some of the vehicles involved supported the application. CCA applications presented a deficiency in these scenarios.

S. Xu et al. [9], evaluate a multi-hop broadcast protocol for the transmission of emergency messages in a highway scenario. This work primarily investigated the successful message delivery while considering the end-to-end delay, without assessing the amount of accidents.

This main contribution of this paper is a detailed study of the impact of concurrent transmissions on the control channel over the performance of CCA applications. This paper evaluates four scenarios with different levels of competition on the control channel. The level of competition on the control channel is influenced by actual characteristics of the roads, such as two-way traffic and roads with more than one traffic lane. These characteristics influence the density of cars and therefore cause greater competition in the control channel, which directly impacts the performance of CCA applications. In addition, we also evaluated the impact of various transmission power levels in the success of CCA applications.

IV. Chain Collisions and CCA Applications

Chain collisions are a frequent problem in traffic, they are caused by the sudden braking of a vehicle. Typically, such braking occurs by technical or human error, leading to a series of sequential collisions behind the vehicle that first braked.

Fig. 1 illustrates a chain collision scenario. Vehicle 1 sees the obstacle in front of him and brakes. The second vehicle only realizes what happened after vehicle 1 starts reacting. The braking only occurs after the reaction time of vehicle 2's driver. This reaction time varies from driver to driver and is influenced by the driver's level of attention.

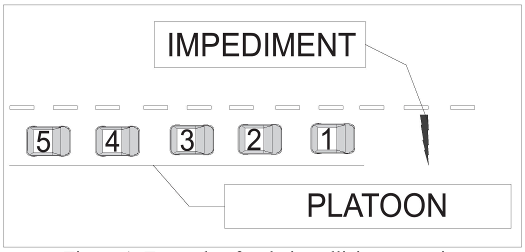

Figure 1. Example of a chain collision scenario.

In this article, we call perception instant the moment the driver perceives the obstacle or the car braking immediately in front him. The reaction time is the time it takes the driver to react after the moment of perception.

J.-B. Tomas-Gabarron et al. [7] mentioned that the reaction time is normally between 0.5 and 1 second. The reaction instant is the moment when the driver begins its braking. Therefore, the reaction instant can be obtained by adding the reaction time of the driver to the perception instant.

Given two vehicles, v1 and v2, that travel in the same direction and in the same traffic lane. Vehicle v2 is right behind v1. When v1 brakes, it lets v2 know through its brake lights. In general, the perception instant of v2's driver is very close to v1's driver reaction time. However, v2's driver will take some time to react. This time depends on the level of attention of v2's driver.

The reaction instant of each driver depends on his own reaction time and the reaction time of all drivers in front him. Thus, the problem of chain collision worsens the more vehicles there are.

Here are some definitions considering that the first car in a platoon of *n* cars brakes sharply.

RI(n) is the reaction instant of the vehicle at position *n*. The time to detect the abrupt braking (*Tdab*) is the time required by the CCA application in the first vehicle to brake. This is interpreted by the CCA application as a high probability of chain collision involving the vehicles that are coming right behind the first one. After that time interval the CCA application sends the emergency message to the cars that are right behind the first one. *TPT(n)* is the transmission and propagation time of the message until it reaches vehicle *n*. *MPT* is the message processing time. *DRT(n)* is the time that the driver spends to react and start braking process (non-automatic) after the instant he identifies the need for braking. The automatic reaction time involves the time the CCA application needs to start the reaction upon the arrival of an emergency message.

The reaction instant of the vehicle at position *n* using the automatic CCA application is defined by $RI(n) = \min\{RI(n-1) + DRT(n), RI(1) + Tdab + TPT(n) + MPT\}$. In this case, the difference between the reaction instants is essentially the difference between the transmission and propagation times to each vehicle in the platoon.

The reaction instant of the vehicle at position *n* using the manual CCA application is defined by *RI (n)* = min {*RI (n-1)* + *DRT (n)*, *I* (1) + *Tdab* + *TPT (i)* + *MPT* + *DRT (i)*}. In this case the difference between the reaction instants is influenced by the manual reaction time of each driver.

The reaction instant of the vehicle at position *n* without using the CCA application is defined by *RI (n)* = *RI (n-1)* + *DRT (i)*. The difference between the reaction instants of each driver is influenced by the manual reaction time of the driver at position *n* and the reaction time of all drivers in front of him.

The difference between the reaction instants of each vehicle in the platoon influences the number of collisions. One solution to minimize this problem is to approximate the reaction instants of the vehicles in the platoon. This can be achieved through the exchange of messages between the vehicle which caused the accident and the other vehicles in the platoon. This is the foundation of CCA applications.

CCA applications start their procedures upon detecting an abrupt braking. The application then sends an emergency message to vehicles behind the vehicle that braked. On the receiving end, upon receiving the emergency message the CCA application can start am automatic braking or simply issue a warning to the driver so that he can start braking.

CCA applications that trigger an automatic reaction on the vehicle are called automatic CCA applications. If the CCA application only sends an alert to the driver then it is called manual CCA application [7].

Fig. 2 illustrates how two vehicles (v1 and v2) get closer due to an emergency braking made by vehicle v1.

At the i1 instant, v1 and v2 are separated by a distance d0. At i2, v1's driver starts braking abruptly (for example, by suddenly realizing there is an obstacle in front of him). Therefore, *RI* (v1) = i2. Still, at i2 v2's driver observes v1's brake lights. It is worth noting that only in the instant i3, i3 = i2 + *DRT* (v2), v2 starts its braking process. At i3, the distance between v1 and v2 is equal to d1, which is smaller than d0.

From the instant i3 onwards, the two vehicles are already slowing down, but v1's speed remains smaller than v2's. Therefore, at the time of stopping (i4) the distance between the two vehicles is d2, which is smaller than d1. The value of d2 might be zero, characterizing the collision of vehicles.

In a scenario with more than two vehicles, the approach between two vehicles happens exactly as showed in Fig. 2 and from time i3 onwards cycle restarts for the next pair of vehicles.

CCA applications are driven towards traffic safety and aim to prevent chain collisions. The CCA application functioning is based on the exchange of emergency messages between vehicles. If the vehicle is using an application automatic CCA application, the vehicle reacts automatically. If the vehicle uses a manual application an alert is sent to the driver, and he is responsible for the braking.

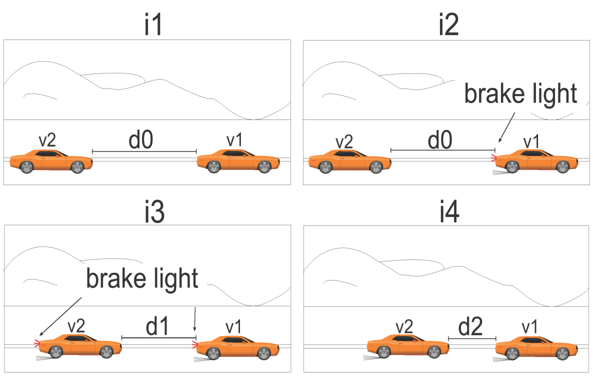

Figure 2. Two vehicles during a braking situation.

V. Performance Evaluation

The performance evaluations were performed with the help of the NCTUns 6.0 simulation tool. This simulator was chosen because of several characteristics: i) it has integrated traffic and network simulators, ii) it has the WAVE protocol stack, therefore directly supports vehicular network simulations and iii) it allows for microscopic modeling, i.e. simulations with traffic parameters and network events defined for each node. All of this is favorable for modeling chain collision situations.

The WAVE architecture, which is implemented in the NCTUns 6.0 simulator, was used for inter-vehicle communications. The WSM protocol was used for sending emergency messages.

Table I shows the traffic parameters and Table II shows the parameters concerning the CCA applications used in the simulations.

The traffic parameters characterize a scenario with high risk of collision. While this it may not occur constantly, this is the kind of scenario where chain collisions usually happen. This situation can be found mostly in medium and big sized cities. Studies have been

TABLE I. Traffic Parameters

Traffic parameters	
Average speed	16 m/s
Number of vehicles on the platoon	30
Average distance between vehicles	10 m
Max deceleration	10m/s²
Vehicle length	3m

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TABLE II. CCA APLICATIONS PARAMETERS

CCA aplications parameters	
Transmission power	21 dBm, 28 dBm, 35 dBm
Transmission rate	6 Mbps
Transmission channel	178 (control channel)
Emergency deceleration detection time	0.4s
Emergency message processing time	0.2s
Driver reaction time	0.5s - 1s

conducted addressing scenarios with different average car speeds to evaluate the influence of speed on the number of collisions.

The number of vehicles generating extra traffic on the control channel was varied to observe the impact of extra traffic on the control channel over the performance of CCA applications.

In addition, we evaluated the impact the signal power used to transmit emergency messages has over the delivery rate of these messages and the number of vehicle collisions.

The header of a WSM contains information on which channel to be used, power and transmission rate associated with each packet enabling the control of these parameters by applying them to each package individually.

To assess the impact of extra traffic on the control channel over the performance of CCA applications we considered four scenarios. Scenario 1 presents ideal conditions, there is no competition on the control channel. In a single traffic lane, there are 30 vehicles with 10 meters of distance between vehicles. Experiments were carried out to evaluate the performance of CCA applications from the moment the first driver in line performs an abrupt braking. The metric of interest is the number of collisions between vehicles.

In Scenario 2, besides Scenario 1 characteristics, we also consider concurrent transmissions on the control channel. On the single traffic lane there are also vehicles providing on average a WBSS every 200 meters. This means that the WBSS provider vehicle periodically sends beacon frames on the control channel. These beacon frames compete with emergency WSM messages from CCA application.

Scenario 3 also considers only one direction of traffic, but has three traffic lanes with vehicles using the control channel. Scenario 4 has vehicles traveling in 6 traffic lanes, 3 lanes in each direction. In scenarios 3 and 4, for each lane at each 200 m there is vehicle providing a WBSS. In all scenarios considered, the platoon of vehicles 30 (discussed in terms of vehicle collision) is present in only one of the

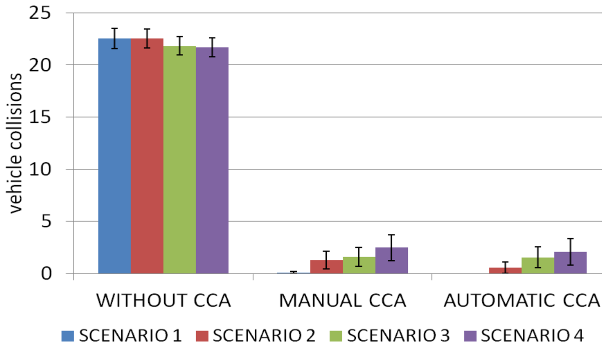

Figure 3. Performance Comparison of the CCA applications in the studied scenarios.

lanes. In all scenarios we assume an average speed of 16m/s. Initially, we assume a transmission power of 28dBm. All results are presented with a confidence interval with a confidence level of 95%.

It is noteworthy that the maximum number of collisions in a platoon of n vehicles is n -1, because in this work we assume that the first vehicle does not collide with any obstacle, therefore the maximum number of collisions in the studies presented is 29.

Fig. 3 shows the performance without the CCA application, and the performance with the automatic and manual application for each of the scenarios.

In general, there is a significant decrease in the number of collisions when the CCA application is used. Without the application over 20 collisions occurred. When the application was put to use at the worst case there were less than 4 collisions.

Fig. 4 shows the manual and automatic CCA performance concerning the number of collisions for each of the 4 scenarios previously presented.

By increasing the number of traffic lanes the number of beacon transmissions on the control channel also increases. The beacon transmissions compete with the emergency messages from the CCA application. The increase of this concurrent traffic on the control channel negatively impacts the performance of CCA applications. This is shown through the increasing number of vehicle collisions as a function of increasing the number of traffic

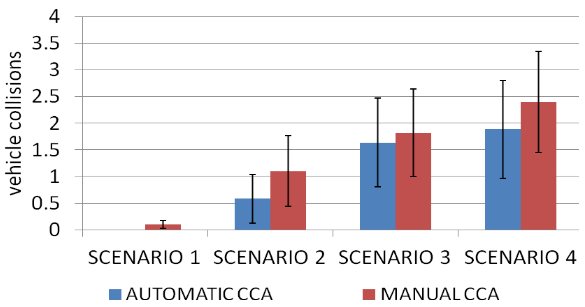

Figure 4. Manual and automatic CCA performance in each scenario studied.

lanes. This behavior occurs in both manual and automatic CCA application. This increased competition in the control channel increases the odds of collisions involving emergency messages frames.

As a direct consequence from the increased competition, there is a decrease in the successful delivery rate of messages from the CCA application, causing more vehicle collisions.

Table III shows the successful delivery rate of emergency messages and its impact over the average number of vehicle collisions in each scenario.

In Table IV, there is a decrease in the successful delivery rate of CCA messages as competition increases in the control channel. For example, in the scenario 4 with 6 traffic lanes, the successful delivery rate is 87.16%, which means a loss of 12.84% of emergency messages. This explains the decrease in the CCA performance. It is noteworthy that this behavior was also observed in Scenarios 2, 3, but with less intensity.

Afterwards, a study was conducted to assess the impact of the WSM messages transmission power over the performance of CCA applications. In this study we considered a scenario similar to the one in scenario 4.

Fig. 5 compares the performance of manual and automatic CCA as a function of the transmission power of emergency messages. Table IV shows successfully delivery rates for each transmission power level used.

Fig. 5 shows that the smallest number of vehicle collisions presented itself with the highest transmission power, 35 dbm.

In Fig. 5, there is a small average number of collisions (below 0.5) with a transmission power of 35 dBm. It's important to point out that 35 dBm represents a longer range and obtained a 91.12% emergency message delivery rate. The CCA application performances while transmitting with

TABLE IV. SUCCESSFUL DELIVERY RATE OF EMERGENCY MESSAGES AND AVERAGE NUMBER OF COLLISIONS IN EACH SCENARIO

Scenarios	Delivery rate	Average of vehicle collisions with automatic CCA aplication	Average of vehicle crashes with manual CCA aplication
Scenario 1	100.00%	0	0.1
Scenario 2	92.78%	0.583333333	1.1
Scenario 3	88.40%	1.633333333	1.816666667
Scenario 4	87.16%	1.883333333	2.4

TABLE III. SUCCESSFUL DELIVERY RATE OF EMERGENCY MESSAGES.

DELIVERY RATE	
21 dBm	90.93%
28 dBm	87.16%
35 dBm	91.12%

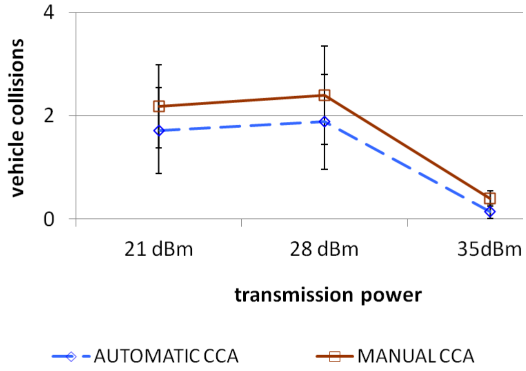

Figure 5. CCA application performance while varying the transmission power.

21dbm to 28 dBm were very close, enough to cause the confidence intervals to overlap.

Through experiments it was found that the extra traffic on the control channel reduces the performance of CCA applications, since the number of collisions increases. This is associated with a decrease in the successful delivery rate of emergency messages. We believe that this increase in the number of emergency messages collisions is strongly related to the hidden terminal problem.

By increasing the transmission power the range also increases. Although it also increases the collision domain on the control channel (which may increase the frame collision probability), the increased transmission power decreases the occurrence of hidden terminals.

The increased transmission power has increased the delivery success rate of emergency messages and consequently improved the CCA application. This behavior, observed at least in the scenarios studied in this article, can be used to point the hidden terminal problem as the main cause of decreased performance of CCA applications in scenarios with concurrent traffic on the control channel.

Fig. 6 illustrates a simplified way how the hidden terminal phenomenon may cause a decrease in the successful delivery rate of emergency messages.

In Fig. 6, vehicle A transmits an emergency message to vehicles coming after it. However, the message collides with beacons transmitted by the vehicle B. As A and B do not know about each other, the CSMA-CA protocol is not very successful in controlling medium access. In scenarios with the higher density of vehicles providing WBSSs the

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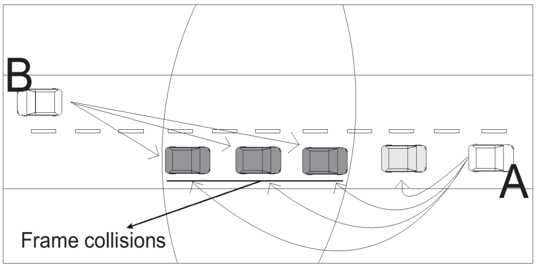

Figure 6: Example scenario with the hidden terminal problem.

occurrence of this phenomenon is more likely. This decreases the performance of CCA applications.

VI. CONCLUSION AND FUTURE WORK

This paper presented a performance evaluation of manual and automatic CCA applications considering four scenarios with different levels of concurrent traffic on the control channel. Generally, at least under the conditions considered in this article, the applications proved efficient, significantly reducing the amount of vehicle collisions.

We identified that with by increasing the concurrent traffic on the control channel the CCA application performance worsens. This effect was caused due to frame collisions, which prevent vehicles from receiving emergency messages sent in WSM packets through the control channel.

The performance of CCA applications as a function of the transmission power was also evaluated. In the studies carried out for this paper, increasing the transmission power decreased the occurrence of the hidden terminal problem and improved the application's performance.

The scenarios where chain collisions can occur are highly diversified. Factors such as the number of vehicles, speed, one way traffic or two-way traffic impact the vehicle density and consequently the level of competition for access control to the control channel.

Studies are being conducted with the goal of minimizing the loss of performance of CCA applications in scenarios with competition on the control channel. These future studies aim to identify further issues with the use of safety applications in VANETs and to propose ways to minimize these deficiencies.

REFERENCES

[1] K.A. Hafeez , L. Zhao, L. Zaiyi, and B.N. Ma, "Impact of Mobility on VANETs' Safety Applications" Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE, December 2010, pp. 1-5.

[2] J. Toutouh and E. Alba, "Performance analysis of optimized VANET protocols in real world tests", Wireless Communications and Mobile Computing Conference (IWCMC), 2011 7th International, July 2011, pp.1244-1249.

[3] D. Jiang and L. Delgrossi, "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments". In Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE, May 2008, pp.2036-2040.

[4] M. Koubek, S. Rea, and D. Pesch, "Reliable broadcasting for active safety applications in vehicular highway networks". In IEEE 71st Vehicular Technology Conference (VTC 2010-Spring), May 2010, pp.1-5.

[5] B.M. Mughal, A.A. Wagan, and H. Hasbullah, "Efficient congestion control in vanet for safety messaging". In International Symposium in Information Technology (ITSim), June 2010, pp.654-659.

[6] T. Taleb, A. Benslimane, and K. Ben Letaief, "Toward an effective risk-conscious and collaborative vehicular collision avoidance system". In IEEE Transactions on Vehicular Technology, March 2010, pp.1474-1486.

[7] J.-B. Tomas-Gabarron, E. Egea-Lopez, J. Garcia-Har, and R. Murcia-Hernandez, "Performance evaluation of a cca application for vanets using ieee 802.11p". In IEEE International Conference on Communications Workshops (ICC), March 2010, pp.1-5.

[8] R. Uzcategui and G. Acosta-Marum, "Wave: A tutorial". Communications Magazine, IEEE, 47(5), May 2009, pp.126-133.

[9] S. Xu, H. Zhou, C. Li, and Y. Zhao, "A multi-hop v2v broadcast protocol for chain collision avoidance on highways". In IEEE International Conference on Communications Technology and Applications, October 2009, pp.110-114.