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Multi-Radio over Fiber Architecture for Road Vehicle Communication in VANETs

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Abstract

Vehicular Ad-hoc Networks (VANET) are employing heterogeneous technologies now a days to meet the increasing demands of Intelligent Transportation System (ITS) applications such as enriched multimedia, video conferencing, gaming and online collaboration. Deployment and maintenance cost for infrastructures are also a major concern. This work proposes a framework, capable of catering multiple technologies simultaneously (such as local area network, wide area networks and cellular networks), that deploys wired and wireless integrated technologies to exploit the advantages of both. Therefore, it offers the architecture based on radio over fiber technology to meet the future requirements of high data rate for Road Vehicle Communication (RVC) in VANETs and it comes up with the most important and perhaps desperately needed feature of 'Future Technology Support' yielding very high data rates support. Several traditionally deployed architectures are striving to come up with the future needs but due to their various limitations they were unable to attain their expected outcomes. The proposed RoF based architecture justifies its need inducing a true value and powerful features to dramatically enhance the overall performance of the entire system. Several evaluation parameters have been chosen that clearly present the strength of proposed RoF framework and prove that RoF framework is the better option for the service providers in the area of ITS applications.

Keywords: ***VANET; intelligent transportation systems; road vehicle communication; radio-over-fiber; radio access unit; central site***

1. INTRODUCTION

There is a lot of work being done in developing various types of Intelligent Transportation System (ITS) applications including road safety, traffic control and numerous entertainment applications[1,2,3]. Service providers are

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deploying heterogeneous technologies[4] following different frameworks for vehicular networks[5] to meet the demands of the users. So, researchers have plenty of projects focusing on premier quality of service with time as demand rise on the top. Some of the mainstream research on vehicular frameworks is carried out by different international standard bodies like IEEE, ISO and C2C Consortium. All these bodies have proposed frameworks for vehicular communication deploying one technology or another but none of these is compatible with heterogeneous technologies (such as local area network, wide area networks and cellular networks) simultaneously. Moreover, the technologies deployed by each framework are also in struggle[6,7] to meet the challenge of high data rates.

As the rapid increase in the number of users demanded 24/7 internet access in the recent years even when moving along the roads in private vehicles, researchers have come to know this is not only the domain of safety applications but multimedia applications[1,2] are the main catalyst to push forward this research and make VANETs a technological mainstream. The proposed Radio over Fiber (RoF) framework employs wireless and fiber integrated solution to take advantage of high data rate support and security offered by optical fiber yielding green communication with the radio interface (named radio access unit) installed along the roads offering support for heterogeneous wireless technologies. The cost effectiveness is also of great deal in the proposed RVC architecture based on Radio over Fiber framework due to its simple RAU design. It offers centralized control having a fewer Central Sites (CS) that makes it easy to manage as compared to existing frameworks.

The remainder of this paper is organized as follows: The next section offers an overview of the existing vehicular communication frameworks proposed by different bodies. Section III presents the proposed solution, identifying the detailed design, implementation and features of the framework. While the breakup of simulation environment is elaborated in section IV and various results of the proposed framework in comparison to different wireless technologies come under evaluation and discussion in section V. And finally concluding remarks are stated in section VI.

2. RELATED WORK

This section will review some popular architectures and frameworks proposed by different bodies for vehicular communication. These can be characterized into three major architectures, WAVE by IEEE, CALM by ISO and C2Cnet by Car2Car Consortium. We will discuss all of these architectures in this section and will strive to investigate what are the shortcomings of each of these architectures as shown in table 1.

The Institute of Electrical and Electronic Engineers (IEEE) recently completed the standards for vehicular networks that were recently released for trial use. Wireless Access for Vehicular Environment (WAVE)[8] is intended to design for safety and short messaging applications but as far as infotainment applications (e.g., media streaming, voice over IP, Internet and mobile multiplayer gaming, flash based web browsing) are concerned, researchers[6,7,9] put some allegations on the capabilities of WAVE (IEEE 802.11p) to provide this kind of services.

Continuous Air interface for Long to Medium range (CALM)[10] by International Organization for Standardization (ISO) was intended to provide vehicle to vehicle, vehicle to infrastructure and Vehicle to other interfaces Communication proving itself a generic framework. CALM recommends infrared for short and medium level distances while for long distances, it prefers to choose among cellular networks like UMTS/GSM but there is not a standard. CALM has kept the option open to opt for the technology among certain communication media to be defined by the working group for CALM but sometimes switching latency is very high[11] to switch from one technology to another.

C2Cnet by C2C Consortium[12] aimed at initiating an open European industry project emphasizing critical security applications supported by European automobile industry. It initially gained popularity for its multiprotocol privilege but due to its limitation for European industry standards it restricted only to European market. C2C-CC also used the CALM idea for multiple interfaces for vehicular communication networks. Moreover, it was also intended for short range communications[12] in vehicular environment.

Table 1. Existing Architecture and Framework

Parameters	WAVE (801.11p)	CALM	C2Cnet
Target Applications	Safety	Non Safety and Critical	Safety
Flexibility	Restricted to single MAC layer	Flexible but has lot of confusions	Flexible to adopt
Promotion Identity	Standard Body	Standard Body	Industry consortium of Car Manufacturers
Future Technology Support	Confined to proposed standards	Up to limited extent by special arrangements	Only protocol privilege
No. of Hops	Single	Single Hop	Single & Multi Hop

3. PROPOSED FRAMEWORK

A Road Vehicle Communication (RVC) system based on Radio over Fiber (RoF) technology is proposed where a Central Site (CS) is interconnected with a larger number of Radio Access Units (RAUs) via optical fibres, and RAUs are deployed along the road to support communication link to vehicles. Vehicles can have multiple interfaces to support communication. A CS is, in turn, connected to backbone network such as public switched telephone network (PSTN) or the Internet.

3.1. Architecture of RoF Framework

An RVC system based on multi-Radio over Fiber (RoF) technology is being proposed in this work where there is a Central Site (CS) that is interconnected with a large number of small base stations named as Radio Access Unit (RAU) via optical link, and these RAU's are deployed along the road to support communication link to vehicles as shown in figure 2. These RAU's are very simple radio antennas covering a tens of meters of range offering transmission from low data rate to a very high data rate without even bothering about the technology being used. The generic architecture of the proposed RoF framework is given in figure 1.

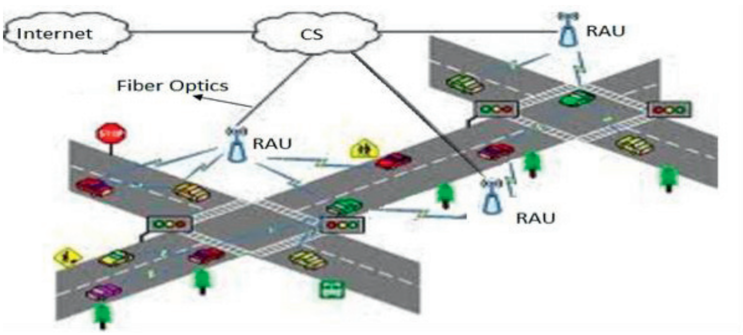

Figure 1: Proposed RoF Architecture

Multimode fiber lets you pass multiple beams of light simultaneously hence various types of signals can simultaneously be transmitted on fiber. As we have to cover larger ranges than that up to few kilometres hence it is a tradeoff choosing between larger range, higher data rates or multiple modes. Equipment of single mode fiber is expensive as compared to multimode fiber hence it is the matter of consideration.

3.2. Design of RoF Framework

A RoF based RVC framework is proposed where both wireless and fiber technologies are incorporated with each other (sometimes referred as FiWi). We have a wireless link between a vehicle and its infrastructure RAU and the radio signal is converted to optical at the radio access unit to send it back to CS that is connected with RAU through fiber link. This conversion is performed again at the CS to get it back to its original form and finally interpreted at the CS for further processing as shown in figure 2.

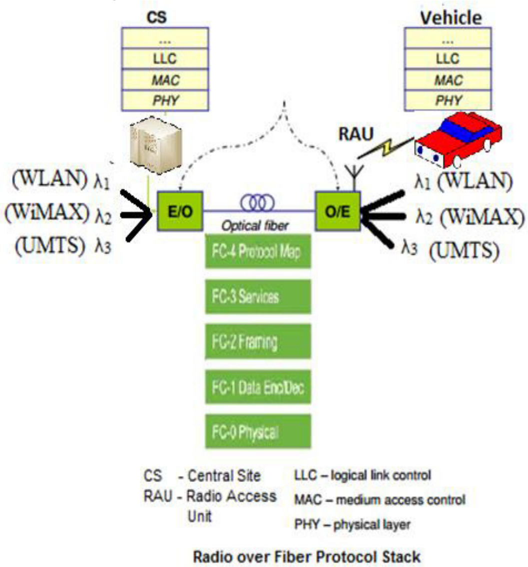

Figure 2: Proposed RoF Protocol Stack

The protocol stack of proposed RoF framework representing the layers of OSI model is given in figure 2. For instance, if we take WLAN signal as λ_1, WiMAX signal as λ_2, UMTS signal as λ_3 and so on then all of these lambdas can simultaneously be transmitted using multimode fiber but it can only offer 1 Gbps up to 1000m and 10 Gbps at 550m ranges[14]. Figure 2 clearly describes the whole process of data packet forwarding and the process on each layer of wireless OSI model against fiber channel layers when it travels through different layers. Data encoding and decoding is performed at fiber channel layer 1, framing is done at the fiber channel layer 2 while various services are performed relating to different tasks at fiber channel layer 3. Similarly protocol mapping is performed at fiber channel layer 4. When the packet is transmitted from WLAN vehicular radio interface to RAU's radio interface, it is travelled through all the layers of 802.11 stack. Similarly if a vehicle is using WiMAX interface to transmit a packet it is travelled through all the layers of 802.16e all the way to RAU's radio interface and so is the case with UMTS.

3.3. Features of RoF Framework

The proposed RVC architecture based on RoF proves itself an essential for future vehicular communication successfully justifying the need of new architecture promising a wide range of important features.
The efforts have been put forward to make it less expensive introducing cheaper RAU's costing about 10 to 12 USD only that has very simple transmission mechanism[15]. This factor is pretty encouraging for the service providers to seriously think about replacing the existing architecture with the proposed RVC system.

Technology independence makes it inevitable to adopt the new RoF based RVC architecture. It is among the most difficult tasks for the service providers to manually change the infrastructure every time a new technology comes in. Hence it needs not bothering about which particular technology is being used to send the signal or which particular frequency is supported by that technology. For example, an RAU does not need to be smart enough to identify either WiMAX signal transmitted at 3.5 GHz or WiFi operated at 2.4 GHz.

People have started using an enormous range of entertainment & multimedia applications with time. Existing infrastructure was able to fulfill the need of light or low data rate applications but real time applications are still a problem and service providers have put various techniques under experiments to support high data rates but they are not reasonably successful. The proposed RoF based RVC architecture can support high frequencies by using fiber optics on the back that can easily support high data rates.

Wireless transmission pollutes the environment by emitting carbon dioxide to the air. Minimizing the use of extensive wireless transmissions may prevent the speed spreading this pollution to the environment where we breathe. There are many other sources as well that have relatively very large share in the carbon pollution as compared to the pollution incurred by wireless communication. Even then this effect should be reduced lying in our capacity. As fiber would be used instead of wireless communication to the CS hence it leads to the fact referred as 'Green Communication'.

The proposed RoF based framework can easily be deployed having minimal control infrastructure in the regions where fiber is already deployed. But as far as those regions are concerned where deployment is required from the scratch and there is no fiber already used as backbone, it can incur very high costs. Thanks to the power of fiber, there are a few number of CS that provide the facility of managing the whole infrastructure as all the processing is carried out on the CS and that is the only centralized control which enables the service provider with the ease of efficient mobility management of the entire network.

4. SIMULATION ENVIRONMENT

4.1. Communication between Vehicle and Infrastructure

This phase configures different communication scenarios that are simulated in National Chiao Tung University network simulator (NCTUns). WLAN, WiMAX and UMTS signals were sent by the vehicles in three different scenarios. The general simulation parameters of different scenarios are as follows:

Table 2: Simulation Parameters

Wireless Technologies	WLAN,WiMAX,3G/UMTS
Standards	802.11p,802.16e,IMT2000
Frequency Bands	2.4 GHz,3.5 GHz,1.9 GHz
Simulation Time	300 Sec
Number of Vehicles	30
Acceleration	1
De-acceleration	4
Speed of Vehicles	55-80 km/hour
Traffic Type	TCP/UDP

This trace files are generated under the /results directory after the simulations are successfully run. These traces are binary file by default to save the disk space as they can grow very large. There is a utility called printPtr that can serve the purpose to make it readable by converting it in a flat text file. This can be done by navigating to the /results directory on Linux shell where that trace file is generated and finally launching the given commands:

```
>>$ cd SimName.results
>>$printPtr SimName.ptr>SimName.txt
```

Assuming that SimName is the name of our simulation and we are in the current working directory, we redirect the standard output to a text file to get the required traffic file that can be further imported to OPNET for the next phase.

4.2. Communication between Infrastructure and Network Backbone

This phase has been broken up into two main parts each having different comparison scenarios.

- Comparison of Conventional Wireless Technologies Infrastructure
- Comparison of Best Wireless Technology with the Infrastructure using Radio over Fiber Framework

We will draw a comparison of the conventional wireless technologies on the basis of different parameters that will be discussed in proceeding scenarios. Following the previous convention, we take into account three wireless technologies i.e. WLAN, WiMAX and UMTS respectively with the same simulation parameters as in table 1 and in both of the above scenarios, five different types of heavy application profiles such as email, file sharing, web browsing, VoIP of GSM quality and video conferencing are applied to generate TCP/UDP data.

5. EVALUATION AND DISCUSSION

5.1. Analysis of Wireless Technologies

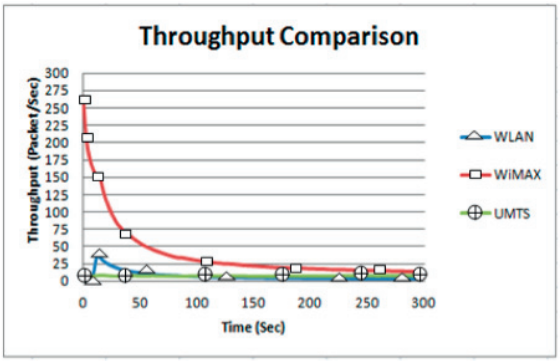

Figure 3: Comparison of Throughput among Wireless Technologies

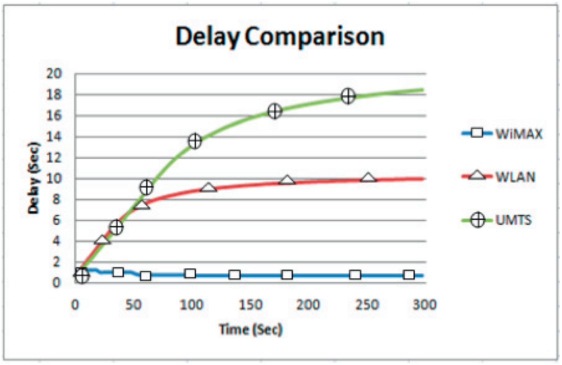

Figure 4: Comparison of End to End Delay among Wireless Technologies

The very first parameter was the throughput in all three the scenarios. Overall Throughput depicts the clear picture where by taking an average we could achieve utmost 35 packets/sec in start-up with this traffic and it was a continuous downfall while the load got increase with time and it eventually fell down to less than five packets a sec in the case of WLAN. Whereas the conventional WiMAX scenario with same network characteristics starts with a reasonable performance offering a few hundred packet/sec but soon after the start, it turned down and as the load of heavy applications increased with time, the performance was effected and finally it could managed to give some twenty packet/sec that was looking to be maintainable.

On the other way round, the conventional UMTS are not looking capable of giving even more than 10 packet/sec on average. Initially the performance was proved to be a bottleneck for conventional UMTS but soon after start it improved reasonably but still has a clear difference against both of the above discussed scenarios. We could clearly observe by the results given in figure 3 that the performance of WiMAX taking throughput as the evaluation parameter is significantly better than both the competitors i.e WLAN and UMTS as it has clearly shown the positive difference in the performance of WiMAX as compared to both the wireless technologies under consideration hence WiMAX is having the clear edge when talking about throughput.

Another parameter that argues for WiMAX to be the best choice among all three wireless technologies is the end-to-end delay. Here we can observe the difference that with the passage of time conventional WiMAX delay has managed to settle itself up to much extent at about seventy percent of a second. While the delay is continuously increasing in the case of WLAN from the start of simulation rising up to tens of seconds as the network gets loaded with such a heavy traffic and packets get stuck and it is causing continuous rise in delay producing an inclined arc settling up at about 10 sec as shown in figure 4. While on the other way round, conventional UMTS have caused an incremental delay of up to few seconds with time that might eventually lead to a higher level of congestion on the network running these applications.

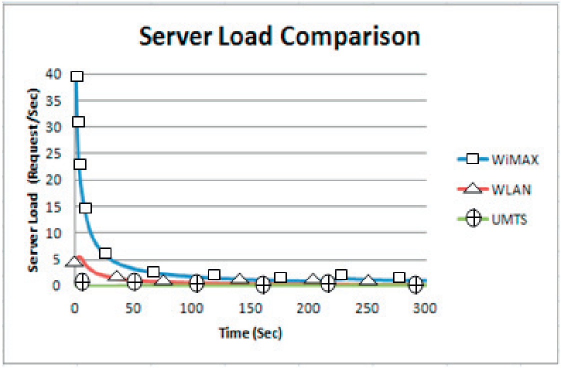

Figure 5: Comparison of Server Load among Wireless Technologies

Load on the server is another significant parameter for the evaluation. This server is responsible for providing all the required services needed by all the five heavy applications running. The server on the load can be checked in terms of tasks/sec but we are taking requests/sec under consideration that clearly interprets the capability of a server serving requests in every second. Here we can clearly observe that the server started from serving above 40 requests/sec but gradually as the load increased it declined to a few requests per second in the case of WiMAX. As far as WLAN is concerned, it started serving 4 to 5 requests/sec but continuously decreased while the load on the network increased with time and could only managed to get less than 1 request in a second. While UMTs is capable of offering 1 request in few seconds as compared to WLAN and WiMAX.

5.2. Evaluation of Radio over Fiber Framework

The simulation scenarios discussed above proved the fact that WiMAX performs best in comparison with other wireless technologies like WLAN and UMTS. Now we are in the position to compare the best wireless technology with the proposed RoF framework to test whether the proposed framework has some advantages over best wireless technology like WiMAX.

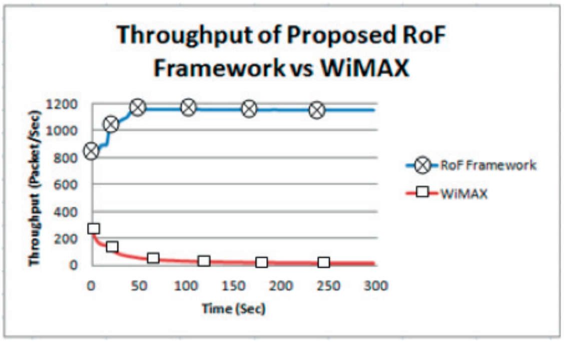

Figure 6: Throughput Comparison for WiMAX with RoF Framework

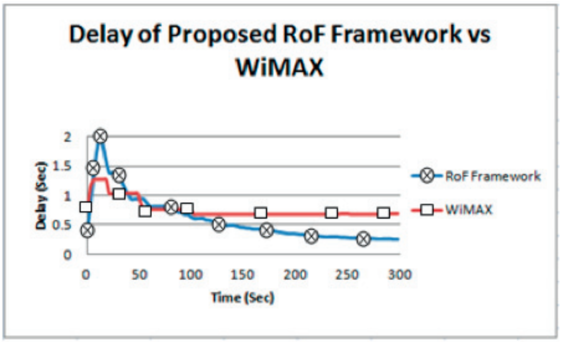

Figure 7: Delay Comparison for WiMAX with RoF Framework

The first parameter is throughput and has clearly described the behaviour of simulation results where fiber offers a far better throughput offering over thousand packets/sec. Throughout from the start of the simulation, the proposed framework offered a reasonably good throughput of 800 packets/sec and went a bit higher with an increase up to over 1200 packets/sec and it is maintaining that rate when the results are taken as average. The conventional WiMAX scenario with same network characteristics starts with a reasonable performance offering a few hundred packet/sec but soon after the start it turned down and as the load of heavy applications increased with time, the performance was drastically effected and finally could managed to give just tens of packet/sec.

It is the second parameter that favours the usage of proposed RoF framework. As we can clearly see using fiber at the back is very much efficient incurring minimal end-to-end delays of less than thirty percent of a second. Initially it started off with a bit more delay up to two seconds but it got adjusted its behaviour with time and declined below the half of a second that is quite reasonable offering overall good performance. While on the other way round, conventional WiMAX have caused a step delay of starting from more than a seconds to seventy percent of a second and looks to go further high with time that might eventually lead to a higher level of congestion on the network by running these applications.

We have examined different parameters in the above simulation scenarios using OPNET and it has been discovered that RoF framework performs well as compared to all the conventional wireless technologies. Throughput and delay were taken as the evaluation parameters and it was very obvious from results that RoF framework gives its best as compared to any other technology like WLAN, WiMAX or UMTS.

6. CONCLUSION

The main objective of this paper is to propose, analyze and evaluate the RoF Framework in comparison with other wireless technologies. We had several parameters under study for different technologies. Throughput and Delay were the key evaluation parameters. The scenarios division was into three main categories (i.e. conventional wireless technology like WLAN, WiMAX and UMTS) and it was proven that WiMAX was best among all these wireless scenarios. WiMAX was further compared with the proposed RoF framework and it was concluded that the proposed RoF Framework performs well in all the circumstances and it can offer to support many future technologies.

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