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In this issue

Technology Developed in GICE

To Improve Spectrum Efficiency via In-Network Computation and Open-Loop in Cognitive Radio Network

from Communication and Signal Processing Group

Introduction

An important characteristics of future wireless communication system is that it consists of 50 billion of devices connecting to the Internet [1]. For the network consists of such amounts of wireless devices, the largest obstacle to scalability and spectral/energy efficiency includes navigation and control overhead. To increase the efficiency of radio spectrum resource to support these devices, cognitive radio has been proposed as a possible solution [2]. However, it also introduces new routing problems due to all the communication link becomes opportunistic. To reduce opportunistic routing and control overhead problem, we propose spectrum map empowered opportunistic routing (SMOR) and open-loop communication [3]. On the other hand, we also provide path-time code which is suitable to dynamic link environment to fulfill error control without feedback information [4]. Instead of exchanging control information and introduce additional overhead, transmitter needs to sensing its environment and get necessary information through computation. Following this design logics, we find that tradeoff between communication and computation. To gain spectral efficiency by computation, which suggests future wireless network design compromises tradeoff between communication bandwidth and computing power under energy constraint.

Spectrum Map Empowered Opportunistic Routing

The spectrum map indicates the available spectrum with the geographic area, acting as the information aggregation platform of all kinds of sensing and inference results to serve cognitive radio ad-hoc network (CRAHN). For regular CRAHNs, we consider a quantized spectrum map as in Fig. 1. On the other hand, to seek more opportunities for CRs' transmissions in large-scale CRAHNs, we study a general spectrum map as in Fig. 2 that reveals the actual sensing

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GICE Honors

Prof.Wanjiun Liao
Y.Z. Hsu Scientific Award-
The Twelfth Scientific
Chair Professor

Prof.Shih-Yuan Chen
2013/2014 Top 10 Reviewers
of IEEE Transactions on
Antennas and Propagation

Message from the Director

Tzong-Lin Wu

Professor & GICE Director

Dear Colleagues and Friends,

Two outstanding professors of GICE share their recent research outcome in the third issue of 2014 GICE Newsletter. Prof. Kwang-Cheng Chen in Communication and Signal Processing group developed a new idea to improve spectrum efficiency via in-network computation in cognitive radio network. Prof. Yi-Jan Chen in Electromagnetic Wave group demonstrates a 77 GHz CMOS Automotive Radar Transceiver with anti-interference function. Both technologies are exciting and promising in future application.
In addition, Prof. Wanjiun Liao of GICE received the 12th Y. Z. Hsu Scientific Chair Professor Award. Prof. Shih-Yuan Chen is ranked 2013/2014 top10 reviewers in IEEE T-AP. Congratulations!
This issue is quite rich and informative. Please enjoy the reading of GICE Newsletter!

Technology

(continued from page 1)

results (i.e., power detection) instead of just two states for quantized maps. By listening to PS-Tx and PS-Rx, CR-Tx then predicts the distance to the PS-Rx from the channel model and obtain the interference to PS-Rx. Such inference scheme can help CR-Tx to obtain the optimal routing path and reduce the interference to PS-Rx simultaneously. From the simulation result in Fig. 3 and Fig. 4, we can find that our proposed scheme can significantly reduce end-to-end delay than other algorithms.

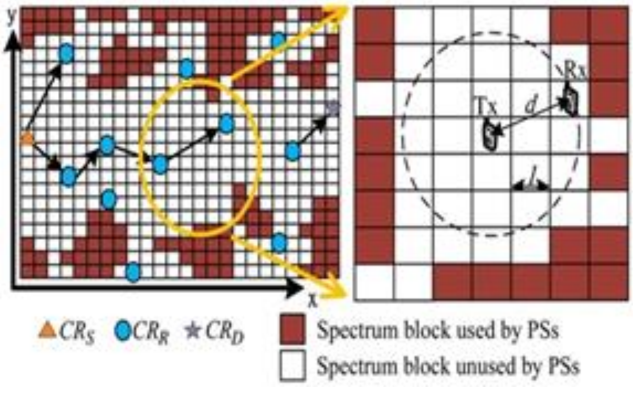

Fig. 1

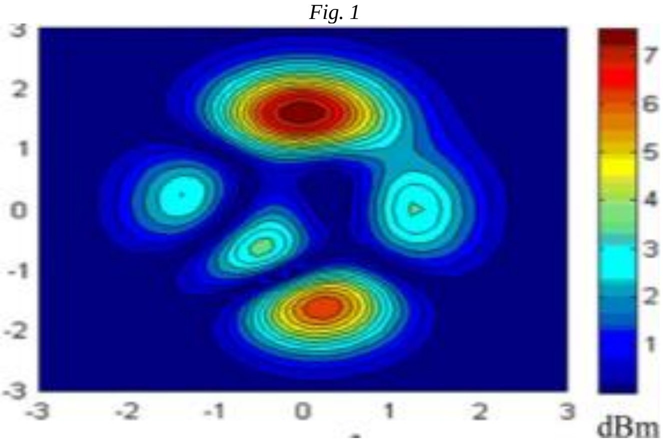

Fig. 2

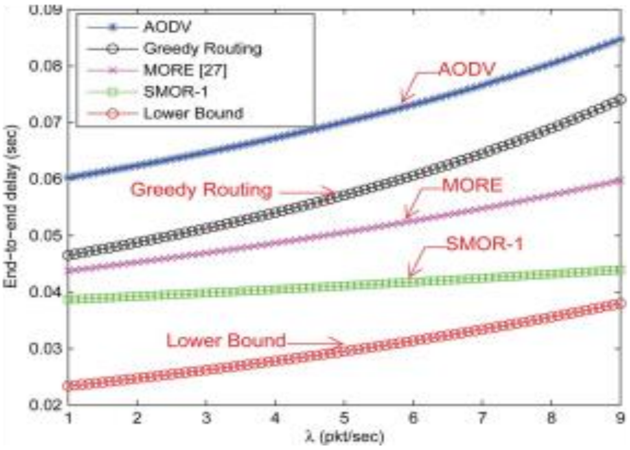

Fig. 3. SMOR can help to reduce more end-to-end delay than conventional routing scheme in CRAHN.

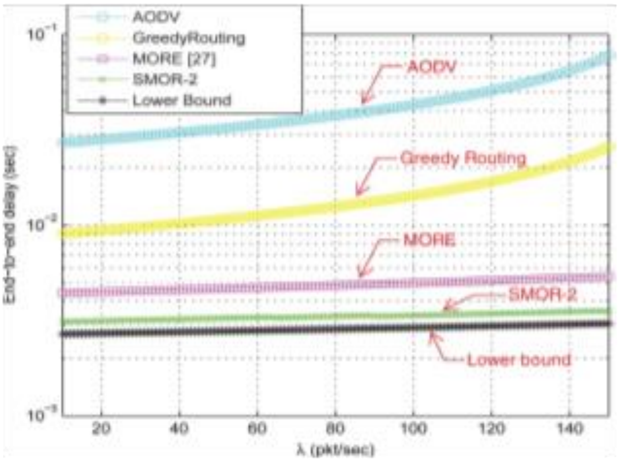

Fig.4: SMOR can help to reduce more end-to-end delay than conventional routing scheme in CRAHN.

Without Feedback Information: Path-Time Code

The opportunistic network like cognitive radio network implies that all the communication links are dynamic and it is hard to practically install feedback error control. In such environment, without the feedback control over wireless link, error control is an open problem. A different way is to apply space-time code in MIMO into the network to solve this problem. As shown in Fig. 5, if we just look at source-destination under multi-hop scenarios, it is a sort of MIMO at the session layer (not physical layer). We can apply space-time codes in the multi-path environment. However, arrival times from different paths are different (or even out of time-to-live), sphere coding scheme can be applied for unknown number of arriving paths. In Fig. 6, we can find that our proposed path-time code can successfully

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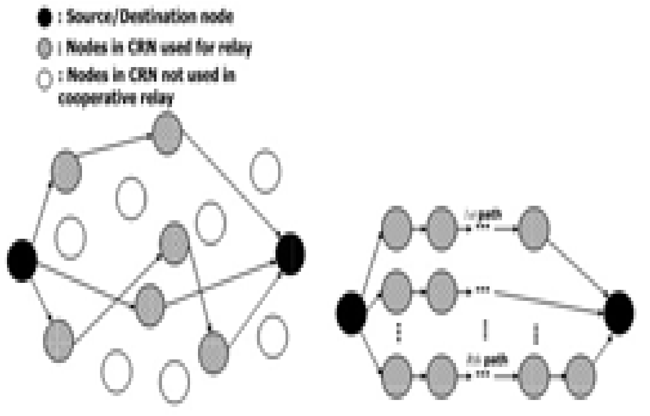
Technology *(continued from page 2)*

complete end-to-end error control in opportunistic multi-hop environment without transmitting additional control overhead.



(a) Example topology of a multi-hop ad hoc CRN.

(b) Equivalent directed graph model.

Fig. 5

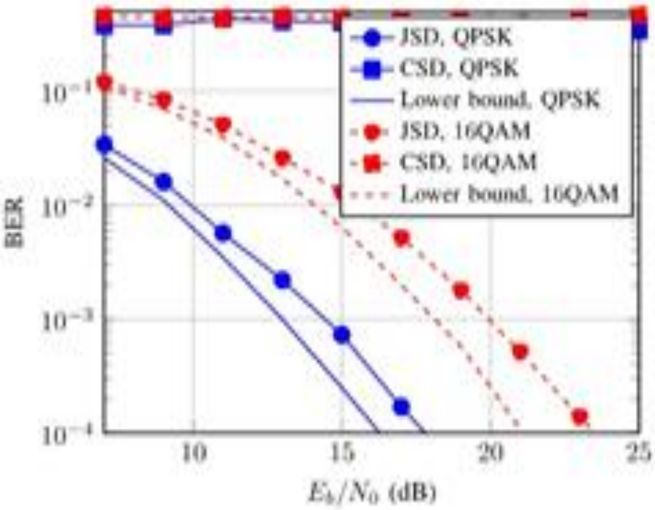


Fig. 6

Tradeoff between Communication and Computation

To improve the spectrum efficiency, an innovative way is to look at the reduction of transmitted data without information loss by possible computations, especially while transmission opportunities are scarce within given spectrum. By observing neighboring transmissions, possible transmitter can make computation (i.e. compression) to reduce traffic to enhance effective information transportation per bandwidth [5]. To achieve traffic reduction, we employed distributive source coding (DSC) via linear code scheme. Instead of transmitting overhead to get information, nodes conducts context-aware computing (DSC), network coding, and local sensing to save communication bandwidth/energy. With the same required delay performance, the computation can reduce the traffic volume in network and improve end-to-end guaranteed throughput in network. As shown in Fig.7, the performance improve about 10dB gain with computation.

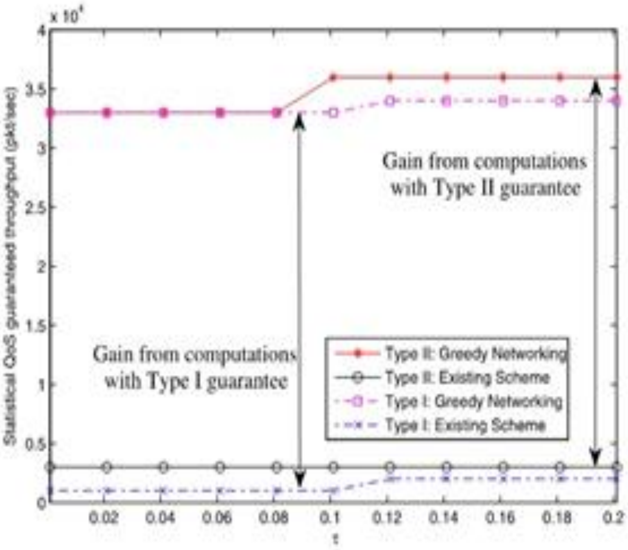


Fig. 7: We can get up to most 10dB gain with in-network computation.

Conclusion

We provide a newly idea that applying computation to estimate and predict the necessary parameters in the network instead of transmitting control signal. The proposed scheme SMOR and the linear coding scheme algorithm to improve the spectrum efficiency of wireless network. The fundamental challenges for spectrum efficiency over large-scale wireless network is addressed by exploiting cognitive radio technology and in-network computation to explore extra available transmission opportunities. The performance is so promising that we can apply these technology into 5G wireless network in the future.

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Technology

A 77-GHz CMOS Automotive Radar Transceiver with Anti-interference Function

from Electromagnetics Group

Introduction

Sensor technologies such as video/ultrasonic, light, and radar had been applied to [vehicles to enhance the driving safety. Millimeter-wave (MMW) radars are superior to the other sensor technologies because they can be well operated at day, night, and most weather conditions. The MMW automotive radars are used for adaptive cruise control (ACC), stop-and-go cruise, blind-spot monitoring, and collision warning (CW) as illustrated in Fig. 1. The long-range radar (LRR) operated at 76–77 GHz for range detection up to 150 meters is used for ACC. The ACC system senses the distance and relative speed of the object vehicle in front of the sensing vehicle to adjust acceleration and deceleration of the latter to ensure safe stop distance. The most commonly used LRR is frequency-modulated continuous wave (FMCW) radar due to its high performance-to-cost (P/C) ratio when compared to frequency-shift keying (FSK) and pulse radars.

Although some LRR transceivers have been demonstrated recently [1]-[3], the issue of mutual interference has not yet been handled. When several automotive radars operate in the same vicinity, the mutual interference from the other radars may lead to false alarm or degradation of sensitivity [4]. The radar signals of the vehicles in the adjacent lanes on the highway may cause interference and ghost target detection. Although narrow antenna beam and different operation frequency can help mitigate mutual interference between radars, those are not very effective to reduce false alarm rate.

This paper presents an integrated 77-GHz CMOS long-range automotive radar transceiver with the capability of mutual interference reduction. The frequency-hopping random chirp FMCW technique is developed to lower the possible occurrence of false alarm by making mutual interference noise-like. The center frequency of the frequency sweep may hop to another frequency at the end of every sweep cycle. Moreover, the chirp bandwidth (frequency sweep range) and slope of frequency sweep can be altered every cycle. The proposed modulation scheme makes the interference signals less likely to be correlated to the desired signal and results in noise-like frequency response for the mutual interference after the received signal is demodulated.

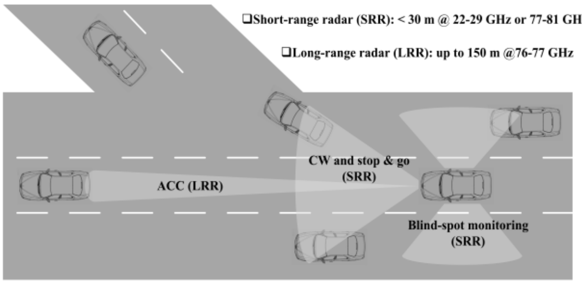

Fig. 1. Applications of MMW automotive radars.

Interference

Mutual interference of radar signals is usually not a concern for short-range automotive radars. However, it becomes a serious issue for long-range automotive radars (LRARs). Although narrow chirp bandwidth can alleviate somewhat the mutual interference of LRARs, it will unfortunately result in coarse range resolution. The working radar transmits the FMCW signal to detect a stationary target and receives its echo after TOF. The interference FMCW signal is received by the working radar after a delay. The interference signal from the other FMCW radar will result in a ghost target and false alarm if the delay is shorter than the possible TOF. The false alarm rate depends on the ratio of the possible TOF to the chirp interval. The longer the chirp interval is, the less likely the false alarm occurs [4].

For the case that the TOF of the working radar signal is 0.6 μs, which corresponds to 90 meters away for the detecting target, and the delay of the interference is 1 μs, the echo signal of the stationary target and the interference signal result in the beat frequencies of 240 kHz and 400 kHz, respectively. The simulated frequency spectrum is shown in Fig. 2.

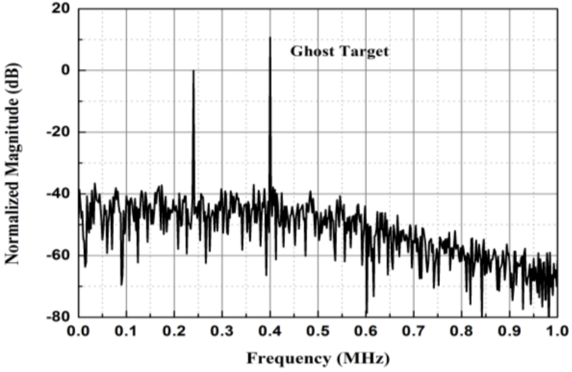

Fig. 2. Frequency spectrum of echo signal and interference.

A method to prevent ghost target detection is the use of different chirp bandwidth or interval. Fig. 3 shows the case of using different chirp intervals for the working radar (1ms) and the interference radar (0.33 ms) while keeping the chirp bandwidth the same. The characteristics of changing beat frequency with respect to time results in spectrum spread-out instead of a steady frequency tone. Therefore, the issue of ghost target detection can be significantly reduced. The simulated wideband spectrum is shown in Fig. 4.

Although the characteristics of changing beat frequency will increase the noise floor slightly, there is no interference tone shown in the output spectrum. Fig. 5 shows the interference suppression and raised noise floor by the use of different chirp patterns with respect to the normalized interference signal power. The chirp sweep time and bandwidth of the working radar signal are 1 ms and 200 MHz, respectively, while those of the interference signal are 0.5 ms and 300 MHz, respectively. Pi/Ps represents the power ratio of

(continued on page 5)

Technology

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the interference signal to the echoed radar signal. The interference can be suppressed to noise level and the suppression level increases along with the power level of the interference signal. The noise floor raised is not noticeable if the power level of the interference signal is about the same as or smaller than that of the echoed radar signal.

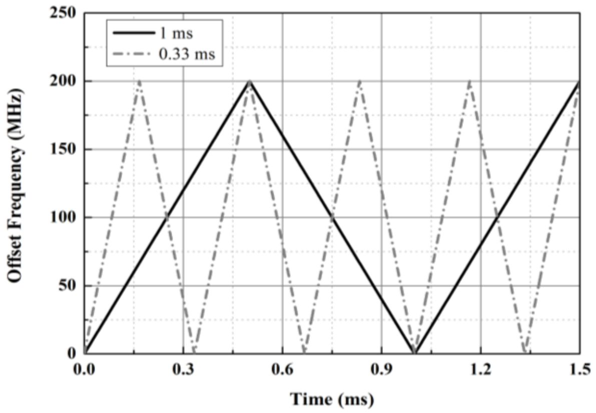

Fig. 3. FMCW signals with the chirp interval of 1 and 0.33 ms.

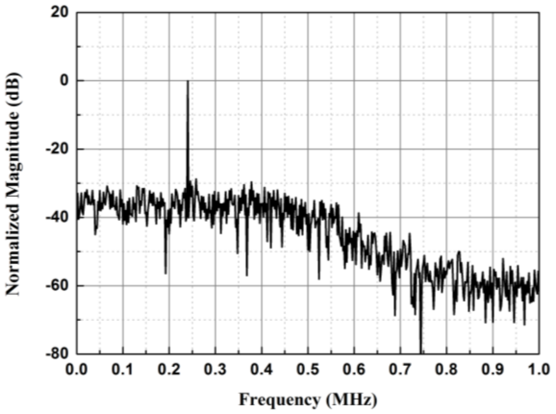

Fig. 4. Frequency spectrum of the echo signal and interference signal with different chirp intervals.

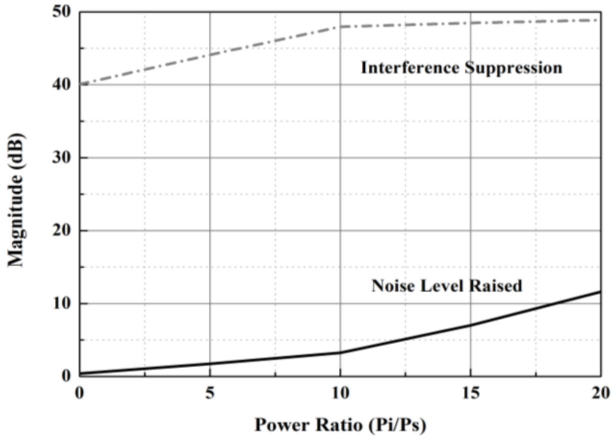

Fig. 5. Simulation results of raised noise floor and interference suppression by the use of different chirp patterns.

Transceiver Design

The frequency-hopping random chirp (FHRC) FMCW technique is proposed for the transceiver design of LRARs to avoid ghost target detection and reduce false alarm rate resulting from mutual interference. The chirp bandwidth, interval, and center frequency of the radar are re-configured every chirp cycle pseudo-randomly such that the possibility of nearby LRARs using the same chirp pattern is extremely low. Fig. 6 shows two examples of the FHRC waveforms (waveform 1 and 2) while the interference signal is kept the same as that shown in Fig. 3 to investigate the effect of the proposed technique. The chirps of the three waveforms within the first 1 ms are deliberately kept the same. After the first chirps, the three waveforms exhibit different chirp bandwidth, interval, or center frequency. The demodulated interference beat frequencies for waveform 1 and 2 are shown in Fig. 7. The interference won't generate a constant beat frequency for both cases such that the interference will result in only higher noise floor but no spurious tone of the ghost target.

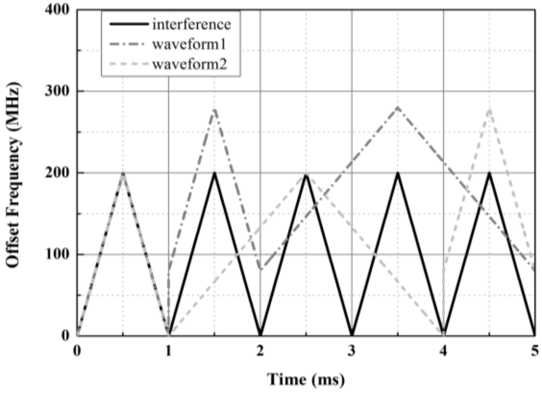

Fig. 6. Example waveforms (1 and 2) of the FHRC FMCW technique to avoid ghost target detection.

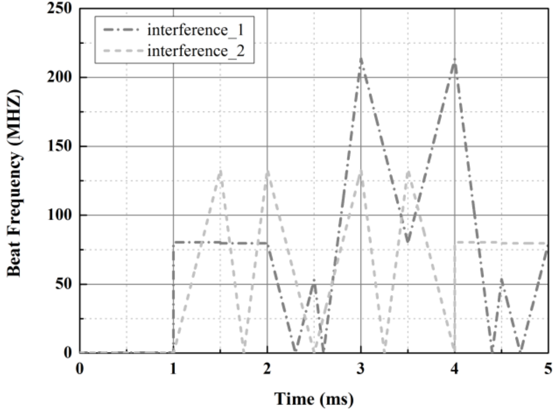

Fig. 7. Demodulated beat frequencies of interference for the two FHRC FMCW waveforms.

The long-range automotive radar system using the proposed FHRC FMCW technique is shown in Fig. 8. The integrated transceiver presented in this paper is shown in the shaded box. The FHRC FMCW signal is generated by the fractional-N synthesizer [5]. The output signal of the VCO is divided by a prescaler and a multi-modulus frequency divider (MMFD), and the divided signal is compared with the reference signal, fref, by a phase frequency detector (PFD). The error signal of the PFD is used to control the charge

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Technology

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pump (CP) and the charge is converted to the control voltage by a second-order low-pass filter (LPF) to control the output frequency of the VCO. The MMFD plays a crucial role in the fractional-N synthesizer. By controlling the average division ratio of the MMFD, the small frequency step and linear FMCW can be generated with a fixed reference source. The control circuits consist of the 16-bit 3rd-order Multi-stAge noise Shaping (MASH 1-1-1) Σ-Δ modulator and waveform generator. The selection of chirp waveform can only be excited after the end of a complete frequency sweep. Two sweeping slopes of 324 and 972 GHz/s can be chosen. In addition, four different combinations of two start frequencies (76.006 and 76.202 GHz) and two stop frequencies (76.496 and 76.692 GHz) can be selected by the other two control bits. With three waveform control bits, totally eight different chirp waveforms are selectable in this design. By changing the chirp waveforms pseudo-randomly, the LRARs can effectively reduce the mutual interference and false alarm rate.

To estimate the reduction of the false alarm rate with the proposed scheme, the typical radar refreshing time of 50 ms is used. The calculated average chirp sweep time is about 2 ms. Thus, there are 25 chirp sweeps before the radar data is refreshed. The working radar processes all the echoed chirp sweeps within the time frame. The false alarm will occur if the interference and working radar signals are coherent for 25 consecutive chirp patterns. There are 8 different chirp patterns to be selected pseudo-randomly, so the false alarms rate can be reduced by roughly 10^{22} times.

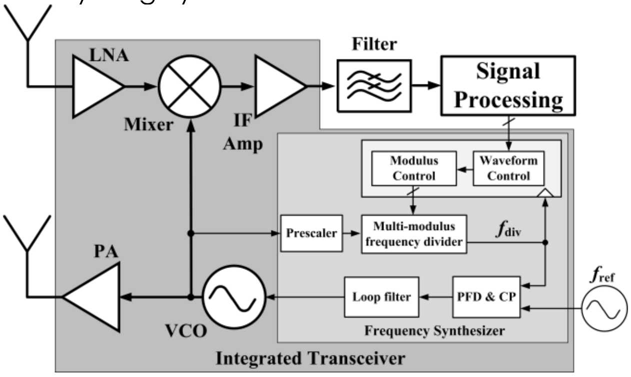

Fig. 8. Proposed long-range automotive radar system.

Measurement Results

The radar transceiver chip was fabricated using the TSMC 1P9M 65-nm digital CMOS technology. The chip microphotograph is shown in Fig. 9, and its overall silicon area is 1.03 × 0.94 mm2. The measured phase noise of the synthesizer at 1.197 GHz is -121.2 dBc/Hz at 1-MHz offset. The FHRC function is tested using the R&S FSV signal analyzer. The FHRC FMCW waveforms with eight different control codes from 000 to 111 are shown in Fig. 10. The overall power consumption of the 65-nm CMOS automotive radar transceiver is 275 mW. The measured average single-side band (SSB) NF and gain are 14.8 dB and 23 dB respectively. The output power of the transmitter is measured using the Agilent E4448A spectrum analyzer and 11970W harmonic mixer. The output power of the transmitter at 76.608 GHz is 6.4 dBm. The performance summaries of the presented transceiver and the recent works of 77 GHz CMOS automotive radar transceivers are listed in Table I. In addition to achieving excellent frequency modulation accuracy, this work is the first 77 GHz CMOS automotive radar transceiver which includes the mechanism for reducing the false-alarm rate resulted from mutual interference.

Conclusion

The low-cost implementation of CMOS technology can make the popularization of long range automotive radar possible, but the radars operating in the nearby area are prone to mutual interference. The frequency hopping random chirp FMCW technique is developed for the automotive radar transceiver to mitigate the effect of mutual interference and reduce the false alarm rate. The proposed technique renders noise-like response for the mutual interference after demodulation. The transceiver circuits are fully integrated using TSMC 1P9M 65-nm CMOS technology. The overall silicon area is 1.03 mm × 0.94 mm and power consumption is 275 mW. The measured RMS FMCW frequency error is smaller than 73 kHz.

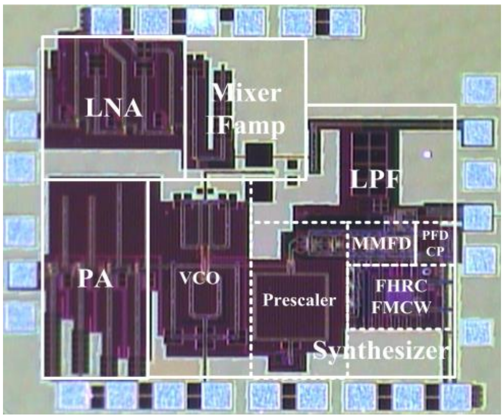

Fig. 9. Microphotograph of radar transceiver chip.

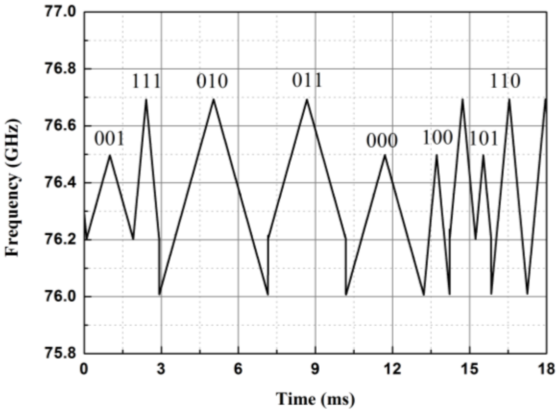

Fig. 10. The FHRC FMCW waveforms.

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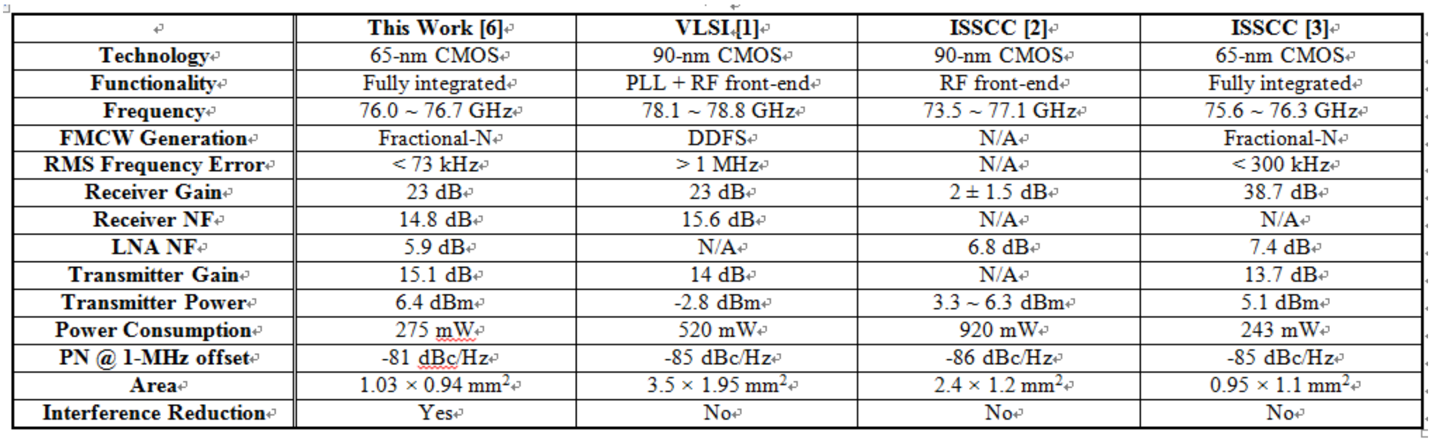
Technology *(continued from page 6)*



	This Work [6]	VLSI [1]	ISSCC [2]	ISSCC [3]
Technology	65-nm CMOS	90-nm CMOS	90-nm CMOS	65-nm CMOS
Functionality	Fully integrated	PLL + RF front-end	RF front-end	Fully integrated
Frequency	76.0 ~ 76.7 GHz	78.1 ~ 78.8 GHz	73.5 ~ 77.1 GHz	75.6 ~ 76.3 GHz
FMCW Generation	Fractional-N	DDFS	N/A	Fractional-N
RMS Frequency Error	< 73 kHz	> 1 MHz	N/A	< 300 kHz
Receiver Gain	23 dB	23 dB	2 ± 1.5 dB	38.7 dB
Receiver NF	14.8 dB	15.6 dB	N/A	N/A
LNA NF	5.9 dB	N/A	6.8 dB	7.4 dB
Transmitter Gain	15.1 dB	14 dB	N/A	13.7 dB
Transmitter Power	6.4 dBm	-2.8 dBm	3.3 ~ 6.3 dBm	5.1 dBm
Power Consumption	275 mW	520 mW	920 mW	243 mW
PN @ 1-MHz offset	-81 dBc/Hz	-85 dBc/Hz	-86 dBc/Hz	-85 dBc/Hz
Area	1.03 × 0.94 mm^2	3.5 × 1.95 mm^2	2.4 × 1.2 mm^2	0.95 × 1.1 mm^2
Interference Reduction	Yes	No	No	No

TABLE I: PERFORMANCE SUMMARY OF 77 GHZ CMOS AUTOMOTIVE RADAR TRANSCEIVERS

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[3] Y.-A. Li, M.-H. Hung, S.-J. Huang, and J. Lee, "A fully-integrated 77GHz FMCW radar system in 65nm CMOS," in IEEE Int. Solid-State Circuits Conf. (ISSCC) Dig. Tech. Papers, Feb. 2010, pp. 216 – 217.

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Activities

PARTNERING FOR TAIWAN'S LEADERSHIP IN GLOBAL NEXT-GENERATION WIRELESS

In developing the next generation wireless broadband market, many countries in Europe, Americas and Asia are actively embracing spectrum sharing policies, technologies and applications, such as Dynamic Spectrum Access (DSA), which leverages unused or underutilized radio spectrum to deliver broadband wireless services. A significant amount of resources have been invested globally to develop this significant new technology. On May 9, 2014, Institute for Information Industry (III), Aviacomm, MediaTek Inc., Microsoft, Communication Research Center (CRC) of National Taiwan University and Power Automation Pte Ltd (PA) jointly announced the establishment of "Taiwan Dynamic Spectrum Access Pilot Group" (DSA-PG.TW). Senior representatives from the six founding partners co-signed the cooperation MOU and officially launched the collaborative effort. The DSA-PG.TW plans to conduct forward-looking field experiments and verification, to develop local competence and international cooperation, in order to commercialize DSA technology. The Pilot Group plans to invite the participation of additional domestic and international partners in order to enhance the innovative power of Taiwan's communications industry. The establishment of the DSA-PG.TW group ushers in Taiwan's active involvement in DSA technology and market development as a leading pilot environment for international collaboration. Together with international ecosystem partners, the Pilot Group looks forward to expanding business opportunities for the Taiwanese industry and maximizing end-user value for the global market. The group aims to facilitate domestic development of DSA products, applications and systems integration, and to develop effective business models, giving Taiwan the leading edge in offering end-to-end DSA turn-key solutions for international export markets.

In addition, experimental data collected by the Pilot Group can provide valuable references for the government of Taiwan for planning related services and regulations, for promoting the adoption of dynamic spectrum sharing technology, for optimizing the efficiency of spectrum utilization in Taiwan, and ultimately making Taiwan one of the leading countries in the new era of dynamic spectrum management and utilization.In the DSA-PG.TW, CRC of National Taiwan University acting as a founding member will attend the regular meeting and technical forum and provide introduction to and advices on advanced research and developments of DSA technology, system and policy for pilot trials.In the following TV white space trial for indoor power meter application, CRC team will provide instruction based on the experience of constructing radio propagation model across floors.

(continued on page 8)

Activities

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The signing ceremony of the Memorandum of Understanding (MOU) for Taiwan Dynamic Spectrum Access Pilot Group (DSA-PG.TW) was held on May 9, 2014 in Ming-Shen ITeS building in Taipei. (From left to right) Dr. Tzong-Lin Wu (Director of CRC, NTU), Mr. Au Bok Soon (Managing Director and President of PA), Ms. Jessie Wang (Sr. Director of Public Sector, Microsoft Taiwan), Dr. Ruey-Bei Wu (CEO of III), Mr. Fred Jann (Deputy General Manager of MTK), Ms. Chenyu Chang (COO of Aviacomm)

The 2014 1st R&D Workshop of Electromagnetic Industry-Academia Consortium on “Small Base Stations for B4G/5G Application”

The 2014 1st R&D workshop of Electromagnetic Industry-Academia Consortium was held at International Conference Hall of CPT Building, National Chiao Tung University (NCTU) in HsinChu, Taiwan, R.O.C., on Wednesday, Apr. 2nd, 2014. The workshop was organized by Taiwan Electromagnetic Industry-Academia Consortium (TEMIAC), Information and Communications Research Laboratories of ITRI, Graduate Institute of Communications Engineering of NCTU and High-Speed RF Front-end Technical Center.

The co-organizers are Smart Network System Institute of Institute for Information Industry (III) and Research Center for Wireless Technology Foresight of NCTU. The workshop was composed of four distinguished sessions and an inspiring panel discussion. Each topic of the four sessions is as follows: The 5G Procedure and the Planning of ITRT Platform, Introduction of 4G Small Cell, The Technologies of MMWave and Antenna Arrays on 5G Wireless Communicating System and The Future of 5G-A Road towards Green RAN. More than 140 participants from the industrious sector,governmental organizations, academic and research institutions attended the workshop and discussed 5G issues. After the four lecture sessions, a panel discussion is provided for the invited experts and audiences to share their opinions mutually. The outstanding speakers from industrious and academic fields, included the president of III Ruey-Beei Wu, Prof. Tzong-Lin Wu (Graduate Institute of Communication Engineering of NTU), Dr. Wun-Jiang Chen and Dr. Ren-Yuan Hu (Information and Communications Research Laboratories of ITRI), Prof. Hwang, Ruey-Bing (Graduate Institute of Communications Engineering of NCTU) and Dr. Jeng-Rern Yang (Executive Board Member, Gemtek), not only addressed the current technical issues, but also brought up the challenges and opportunities over the upcoming years on B4G/5G applications in Taiwan.

The workshop provided a good chance for students to broaden their vision on 5G technology. Along with the irreversible development of globalization, the workshop also inspired a deeper understanding about Taiwan’s position on the 5G market in the future in audiences.

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