Broadband Wireless Communication Technology Development Proposal

(Business Proposal)

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GScom

Table of Contents

1 Introduction

With the advent of Wi-Fi, WiMax, and LTE technologies in 4G networks, the backhaul or small cell business grows explosively. With 4G and the anticipated next generation systems, the coverage range of each cell (or base station) is reduced, the number of cell is increased, and the data throughput is increased significantly. As 4G capabilities are added to 3G networks, cell site backhaul and aggregation network requirements rises from hundreds of megabits/second into the gigabits/second of capacity range.

High speed data, high spectral efficiency, and reliability are getting more and more important technical decision factors in a 4G communication business. GScom has developed in MATLAB a broadband wireless 4096-QAM modem for Gigabit data communication and a variety of wireless communication core component technologies. GScom is working on development of the wireless 4096-QAM modem product using custom designed Field-Programmable-Gate-Arrays (FPGAs).

GScom's wireless communication core technologies and 4096-QAM modem address a wide variety of system-level challenges in wireless communications, including performance with very high speed (up to Giga bps) data communication in a broadband spectrum ranging from cellular band frequencies up to microwave or millimeter wave band frequencies.

GScom's wireless 4096-QAM modem yields the most reliable and the best performance in a broadband wireless backhaul communication channel in the small cell or macro cell communication network systems.

GScom has two objectives in this proposal to you: The first is to get your investment to secure the broadband wireless 4096-QAM modem product using FPGA. The second is to sale our technology license or to provide our technology development consulting service to you.

Under the broadband wireless 4096-QAM modem development program, GScom has two development stages in the development program: The first is to secure the modem using FPGA and the second stage is to secure the modem using ASIC. In this proposal, we will deal with the modem development using FPGA. Under our estimation, GScom needs about 134 MM(man-months) and $2.3M USD to secure the commercial product of the broadband wireless 4096-QAM modem about 15 months after the activation of the development project.

For the technology license or technology consulting service program, GScom provides our customers with system solutions and consulting services for leading-edge communication systems. GScom has available a broadband wireless 4096-QAM modem for Gigabit data communication providing a broad spectrum of wireless communication core technologies and intellectual properties. GScom's innovative technology leadership combined with our innovative design services experience enables our customers the ability to rapidly and effectively innovate, differentiate and win in their markets.

2 Wireless Communication Backhaul Market Trend

With the introduction of smart phones along with 4G systems, wireless networks has evolved to next-generation packet architectures capable of supporting enhanced broadband connections. Simple text messaging and slow email downloads are being replaced with high-speed connections that support real time video, streaming music, and other rich multimedia applications. The 4G and wireless networks will soon approach unobtainable broadband speeds to continue the perceived “user experience” currently provided by the traditional DSL and cable modem wire-line services.

From the wireless operator’s perspective, the 4G and anticipated next generation systems are more efficient at using valuable wireless spectrum. These spectral efficiency improvements support new high-speed services, larger numbers of users, and will generate more revenues with a given frequency spectrum.

With the advancement of the wireless communication technology along with its application, a wide range of the carrier frequency spectrum is used (for example, from cellular band to millimeter wave frequency band) due to the availability of the spectrum and its cost. In general, the higher carrier frequency is used, the higher phase noise is generated.

GScom has developed a broadband wireless 4096-QAM modem for high spectral efficiency that can support a wide range of carrier frequency spectrums (i.e. cellular band to 80GHz).
The modem has:

1. World-best (lowest) receiver sensitivity in an AWGN and in a fading environments
2. Achieved approximately 1-2dB within the theoretical BER (bit error rate) curve in AWGN
3. Achieved 8-10 dB coding gain from Forward Error Correction (with using LDPC on 8640 code length)
4. Achieved an additional 2-4dB coding gain above the achieved LDPC coding gain (as listed in #3) by using Reed-Solomon (R-S) FEC with RS(255,235,20) format (when used in a cascaded form of the R-S and LDPC codes)
5. Very robust to phase noise (6-8dB performance improvement)

3 Broadband Wireless 4096-QAM Modem

3.1 Introduction

GScom developed in MATLAB a broadband wireless modem to achieve Giga bps (bits per second) range high speed data communication for both microwave and mm-wave radio systems. The broadband wireless modem is a single carrier QAM modem for spectral efficiency and can be used in broadband wireless communication systems for fixed wireless backhaul communication, cellular access networking, or small cell backhaul communication. The broadband wireless modem supports modulation levels up to 4096-QAM, developed for point-to-point or point-to-multi point microwave and mm-wave radio systems. The broadband wireless modem achieves the high speed data communication capability through advanced technology development in the modulation, coding, signal processing, and system operation areas.

3.2 System Features

The main features of the 4096QAM Modem IP Core are:

- Modulation schemes: 4QAM/16QAM/64QAM/256QAM/1024QAM/4096QAM
- Channel bandwidth: 14/28/56/112MHz
- Maximum symbol rate on each of the bandwidth: 12.6/25.2/50.4/100.8 MSym/second
- Real time Gray code mapper/de-mapper with very low latency LLR decoding
- R-S (Reed-Solomon) Codec with (N,K,S) format used
    - Block length; N = 255
    - Data length; K is variable
    - Number of parity bits: S = 2t, where t is the number of correctable bits
    - Parallel pipelined structure Reed-Solomon (R-S) codec
- LDPC (low density parity check) codec
    - Code length: 4320/8640 bits & Coder rate: 0.5 & 0.75
    - Architecture Aware Parallel TDMP architecture
    - Horizontal and Vertical Partitioned LDPC
    - Optimized node degree distribution LDPC
- Fractional spaced DFE (decision feedback equalizer) combined with carrier recovery (CR).
- Joint estimation & correction of the phase noise using the DFE combined with CR.
- Pulse Shape Filter (PSF): Squared-Root-Raised-Cosine with 96 taps FIR
- Roll-Off factor in PSF: 10% - 18%
- Internal BER tester
- ACM, HARQ, ATPC, XPIC, etc.,

3.3 Performance [1]

The performance degradation of the digital radio systems is caused by the combination of the following performance degradation factors: interference, thermal noise, phase noise, and waveform distortion due to the multipath propagation in the fading environment.

GScom carried out a system performance simulation to test the performance of the 4096QAM modem in an AWGN environment and in a fading environment. GScom uses LDPC codec for low order QAM modulated signals (from QPSK up to 256-QAM signals) and uses a concatenated code of the LDPC and R-S codecs for high order QAM modulated (1024-QAM and 4096-QAM) signals. GScom used a LDPC (code rate of 0.5, code length of 8640) and a RS(255,235,20) format of the R-S code in the simulation test.

The following table shows the receiver sensitivity of the 4096QAM modem in each QAM modulation format in AWGN environment.

Receiver Sensitivity in AWGN environment (using LDPC and R-S code)

Modulation Format	4QAM	16QAM	64QAM	256QAM	1024-QAM		4096-QAM	
					w/o R-S	w/ R-S	w/o R-S	w/ R-S
RCVR Sensitivity	6 dB	13 dB	20 dB	25 dB	30 dB	28 dB	36 dB	32 dB

The following table shows the performance improvement of the modem due to the usage of the LDPC codec.

LDPC coding gain in reference to 1e-6 BER

	4QAM	16QAM	64QAM	256QAM	1024QAM	4096QAM
AWGN	7 dB	7 dB	6 dB	8 dB	8 dB	9 dB
PN+AWGN w/CR	7 dB	7 dB	6 dB	7 dB	5 dB	5 dB

NOTE: BER=bit error rate, AWGN=additive white Gaussian noise, PN= phase noise
CR= carrier recovery using digital phase locked loop for phase noise mitigation

The following table shows the receiver sensitivity of the 4096QAM modem, in the frequency selective fading environment, obtained from the performance test using the system parameter specified in the specification.

Receiver Sensitivity of 4096QAM modem in compliance test with specification (ETSI EN 302 217-2-1)

Modulation Format	4QAM	16QAM	64QAM	256QAM
Receiver Sensitivity (dB)	6 dB	13 dB	20 dB	26 dB

GScom's 4096QAM modem provided almost the same receiver sensitivity in the frequency selective fading environment as those obtained in the AWGN environment. The GScom's 4096QAM modem provided excellent performance in the frequency selective fading environment which is specified in the specification.

The following tables show the receiver sensitivity and the coding gain of the 4096QAM modem in each QAM modulation format in an aggressive frequency selective fading environment.

Receiver Sensitivity in aggressive frequency selective fading environment (using LDPC and R-S codes)

Modulation Format	4QAM	16QAM	64QAM	256QAM	1024-QAM		4096-QAM	
					w/o R-S	w/ R-S	w/o R-S	w/ R-S
RCVR Sensitivity	7.5 dB	13 dB	20 dB	26 dB	31 dB	29 dB	37 dB	33 dB

Coding gain of the LDPC & R-S codes in reference to 1e-6 BER

	4QAM	16QAM	64QAM	256QAM	1024QAM	4096QAM
LDPC code	7 dB	8 dB	8 dB	7 dB	7 dB	7 dB
R-S code	NA	NA	NA	NA	2 dB	3 dB

As seen in the receiver sensitivities in AWGN and those in the frequency selective environment, the performance degradation of the GScom's 4096QAM modem in an aggressive frequency selective fading environment is at most 1 dB when compared to those in the AWGN environment. GScom's 4096QAM modem provided excellent performance in an aggressive frequency selective fading environment.

The GScom's 4096QAM modem provides very reliable functionality and excellent performance while being very robust to any kind of noise such as AWGN, phase noise, fading, etc.

4 Business Proposal

GScom has two business models. The first is the manufacture and sale of broadband wireless 4096QAM modem products using custom designed Field-Programmable-Gate-Arrays (FPGAs). GScom developed in MATLAB the broadband wireless 4096QAM modem. GScom needs to get investment money to implement the modem into the FPGA hardware, test, and make it a commercial product as soon as possible. The second is the sale of GScom's technology and/or to provide technology development consulting services.

4.1 4096-QAM Modem Development

4.1.1 Summary

GScom has developed a broadband wireless modem for Gigabit data communication for both microwave and mm-wave radio communication systems using MATLAB. GScom is working on the development of a wireless 4096-QAM modem product using custom designed Field-Programmable-Gate-Arrays (FPGAs). GScom has conducted a project analysis for the commercial product and has concluded the project needs financial support of approximately $2.5M USD to develop a commercial product of the 4096-QAM modem within 15 months once the project is initiated. GScom is looking for investors or business partners to secure the investment money of the $2.5M USD to develop a very reliable, world-best, and economical system solution for Gigabit data communications.

4.1.2 Baseline Design

The baseline of the broadband wireless 4096-QAM modem has been developed, verified in MATLAB, and is based on the digital baseband solution as documented in the modem system document [1].
If you want to change important system specification from the initial design we can discuss with you before we implement them in the commercial product.

4.1.3 Project Tasks

This section provides an overview of all required project tasks, together with an assessment of the effort required.

TASK 1: Project Management

- project documentation
- managing resources
- highlighting and resolving critical issues
- regular reporting and teleconference discussion with customers and investors

TASK 2: System Architecture Design

- high level design of all blocks, enabling kickoff of detailed design activities
- system design and specifications
- HW implementation and specifications
- SW implementation and specifications
- interface specifications

TASK 3: Prototype Board Design

This task will design the prototype board for the broadband wireless 4096-QAM modem, including the Input Interface, Output Interface, FPGA and Operator physical interface.

Prototype board design:

a. input/output at 70-700 MHz IF
b. bandwidth selectable up to 112 MHz
c. modulation selectable from QPSK up to 4096 QAM
d. E1/T1, STM-1, and 1000BASE-T interface module

The design goal is to support all end customer requirements with a single board layout, possibly requiring a selection of filters or other components in order to comply with the requirements of a given specific installation.

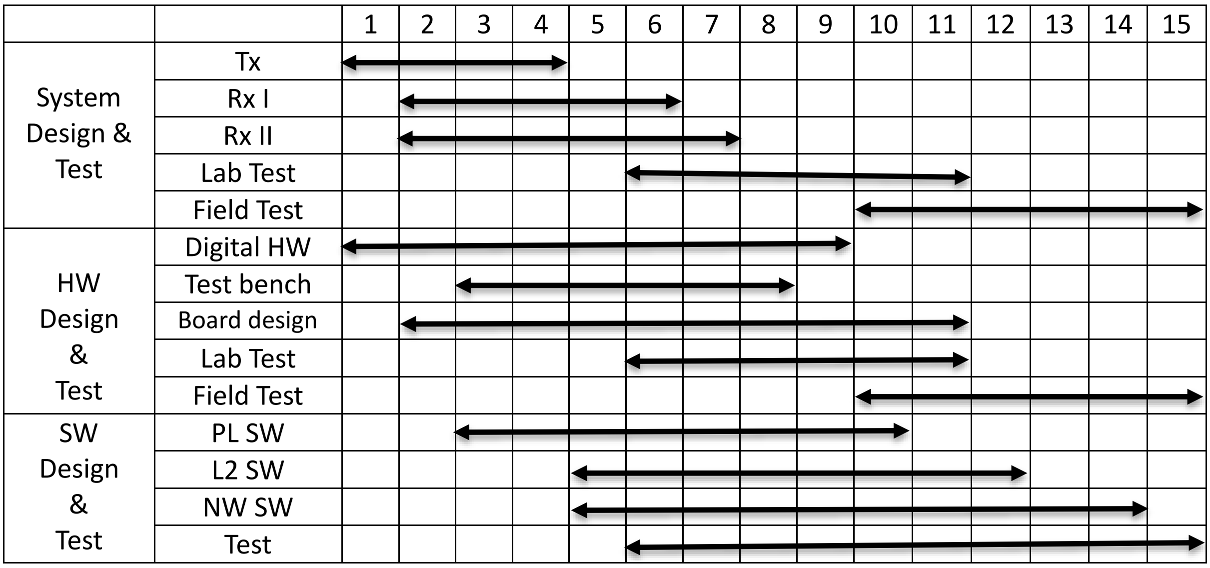
TASK 4: Design of the Modem Core Blocks
The main functionality of the modem is implemented as IP Core on the target FPGA. In this task, GScom shall design and verify all functional blocks required for the final product. Analysis and tradeoffs shall be made using both MATLAB simulation models and where necessary by implementation in Verilog and downloading onto the target FPGA on the prototype boards. The functional blocks of the modem are described on Figure 7 & Figure 8 in the modem system document [1].

TASK 5: Software Design
- Physical control software
- MAC/Ethernet OAM software
- Network communication software

4.1.4 Project Plan, Milestones and Deliverables

4.1.4.1 Project Plan

<u>It will take 15 months to make the broadband wireless 4096QAM modem product available in the market after the kick-off the project.</u> Figure below shows the top level planning of the tasks required to complete modem development project.



4.1.4.2 Milestones

- Systems Design (Fixed Point): by 7 month after kick-off
- Hardware Design: by 9 month after kick-off
- PL control software Design: by 10 month after kick-off
- Lab Test: by 11 month after kick-off

- L2 Software Design: by 12 month after kick-off
- Field Test & Commercial Product: by 15 month after kick-off

- Interim Design Review Meeting I: by 5 month after kick-off
- Interim Design Review Meeting II: by 7 month after kick-off
- Interim Design Review Meeting III: by 10 month after kick-off
- Interim Design Review Meeting IV: by 12 month after kick-off
- Final Product Meeting: by 15 month after kick-off

4.1.4.3 Deliverables

- Weekly progress report
- Regular meetings with investors: nominally every month
- Minutes of meetings with action items: within 1 working day after each meeting
- All relevant technical documentation, including design tradeoffs, performance results etc.
- Full documentation for presentation at the interim Design Review Meeting, at the latest one week before the meeting date

4.1.5 Financial Proposal

4.1.5.1 Project Budget

The project budget consists of employee salary, design tool license fee and test equipment rental fee, prototype board production fee, and office rental and maintenance fee. The major part of the project budget will be allocated to employee salary. Based on the project plan and milestone in Section 4.1.4, Modem development activities will require in total 134 man-months for the development of commercial broadband wireless 4096QAM modem products (refer to the document attached for detail) [2].

Summary of the budget is as follows (refer to the document attached for detail) [3]:

- Employee salary & Benefit: 1,742K USD
- Design tool & test equipment rental fee: 310K USD
- FPGA prototype board (3 sets): 60K USD
- Office rental and maintenance fee: 180K USD

Total project budget required for 4096QAM modem development: 2,292K USD

4.1.5.2 Change Management

Should significant deviations occur in project activities due to the amendments in initial specification, substitution of tasks, timelines and budget or due to any other objective circumstances, GScom will immediately inform Investors about such deviations. In such cases, parties will seek in good faith ways to address deviations and may introduce amendments to the negotiated terms and conditions if this deems necessary.

4.1.6 Project Organization

Project is functionally organized around the positions indicated in table under Section 4.1.4.1. Administrative management is performed by Project/Account Manager, R&D task leadership is carried out by VP of Systems Engineering & VP of Hardware Engineering.
Project/Account Manager for this project is Dr. Sanguoon Chung (schung@gs-communication.com, Phone: +1-858-776-0290).
VP of Systems Engineering is Dr. Stash Czaja (phone: +1-619-857-0141).
VP of Hardware Engineering is Mr. Steve Maire (phone: +1-760-445-9382).

4.2 Technology Licensing

GScom has developed in MATLAB a broadband wireless 4096-QAM modem for Gigabit data communication systems, along with a variety of wireless communication core component technologies, or intellectual properties (IP), which are available for purchase and/or licensing.
GScom's wireless communication core technologies and 4096-QAM modem address a wide variety of system-level challenges in wireless communications, including performance with very high speed communication in a broadband spectrum ranging from cellular band frequencies up to microwave or millimeter wave band frequencies.

The modem provides very reliable, stable, and excellent performance in any channel impairment conditions, including tough phase noise environments. The modem has shown excellent performance:

1. World-best (lowest) receiver sensitivity in the AWGN and in the fading environments
2. Achieved approximately 1-2dB within the theoretical BER (bit error rate) curve in AWGN
3. Achieved 8-10 dB coding gain from Forward Error Correction (with using LDPC on 8640 code length)
4. Achieved an additional 2-4dB coding gain above the achieved LDPC coding gain (as listed in #3) by using Reed-Solomon (R-S) FEC with RS(255,235,20) format (when used in a cascaded form of the R-S and LDPC codes)
5. Very robust to phase noise (6-8dB performance improvement)

The wireless communication technologies for sale or licensing are as follow:

- **Broadband wireless 4096 Modem (as a system package solution) [1]**

  The broadband wireless 4096-QAM modem is equipped with a powerful LDPC codec, Reed-Solomon codec, and advanced Decision Feedback Equalizer (DFE) which is combined with a Carrier Tracking Circuit. The modem supports 4-QAM, 16-QAM, 64-QAM, 256-QAM, 1024-QAM, and 4096-QAM modulation-rates, combined with LDPC and Reed-Solomon codecs. The modem also supports large dynamic range (100dB) Automatic-Gain-Control (AGC), power control, cross polarization interference cancellation (XPIC), and Adaptive Coding and Modulation (ACM).

  The modem is designed to perform high speed data communication with reliable quality in any harsh communication channel environment and to support the usage of any carrier frequency (from the cellular band carrier frequency up to the millimeter-wave band carrier frequency (80 GHz)). Performance testing of the modem shows the modem to be within 1-2 dB or 3-4dB away from the theoretical BER curve, depending on the modulation technology and channel condition used [1]. The modem also provides the world-best (i.e. lowest) receiver sensitivity in any channel environment [1].

- **Communication Core Component Technologies**

  Technology used in wideband communication systems require high coding/modulation gain, very short latency, and real time processing as much as possible. GScom has developed these core component technologies for application in Gigabit-class wireless communication systems. Some of the typical core component technologies developed by GScom are listed below.

  - **R-S (Reed-Solomon) Codec [4]**

  R-S code is one of the most powerful linear block codes and is optimized for the burst error correction. The Reed-Solomon code provides a compromise between efficiency and complexity, so it can be easily implemented using hardware or FPGA. GScom has developed a Reed-Solomon codec which provides real time processing speed by exploiting the following R-S codec architecture, system parameter, efficiency and hardware complexity:

- Pipelined division architecture for fast encoding
- Parallel pipelined architecture for syndrome calculation for fast decoding
- Parallel pipelined architecture for error location search for fast decoding

◆ LDPC (Low Density Parity Check) Codec [5]

LDPC is the one of the most powerful linear block codes in terms of performance (coding gain). LDPC decoding algorithm is inherently parallel which is attractive for high-speed applications. GScom has developed a custom LDPC codec (encoder/decoder) using the following LDPC architecture and technologies:

- Architecture aware LDPC for low complexity and fast encoding
- Architecture aware parallel TDMP for low complexity and fast decoding.
- Horizontal & vertical partitioning LDPC for low complexity and fast decoding.
- Optimal node degree distribution LDPC for best performance with optimum complexity.
- Achievement of 8~10 dB coding gain with a code length of 8640 and a code rate of 0.5 in the reasonable SNR ranges for data communication.

◆ Mapper/De-mapper (Slicer) [6]

The Mapper takes the coded bit stream at the output of the (LDPC) encoder and maps each group of m bits into one of the M(= 2^m) signal constellations. The De-mapper receives the demodulated symbols from the demodulator and converts the received symbols into the soft decision values of the corresponding bit stream through a soft decision decoding process.

- **Mapper/De-mapper for QAM from 4-QAM up to 4096-QAM modulation level.**
  GScom has developed a real-time adaptive and selective mapper/de-mapper for various QAM modulation levels.

◆ Equalizer combined with Carrier Recovery [7]

Fading, inter-symbol interference, time varying channel characteristics, large dynamic range of signal to noise ratio (SNR), etc., are major signal impairment factors in the broadband wireless communication systems. Phase noise is also one of the most critical signal impairment factors in wireless communication systems which use high carrier frequencies with high-order M-QAM such as 256-QAM, 1024QAM, or 4096-QAM modulation technologies.

GScom has developed an advanced fractionally spaced Decision Feedback Equalizer (DFE) which is combined with the carrier recovery circuit. The carrier recovery combined with the DFE is a powerful solution to fight against phase noise achieved by reducing latency between phase noise estimation and correction. The GScom equalizer yields an excellent performance in any channel environment including any fading environment in addition to the white noise and phase noise environments [1] [7].

◆ AGC (Automatic Gain Control) [8]

The signal in a wireless communication channel experiences a large dynamic range of signal variations due to channel conditions, weather conditions, flat fading, and shading effect of the communication environment.

GScom has developed several types of AGC in terms of accuracy, HW simplicity, and reliability based on the following common AGC specification:

- Input signal dynamic range of 100 dB

- Flat fading rate of 100dB/sec
- Output signal level of 20dBm+/-3dB.

◆ Time Tracking (Symbol tracking & Frame tracking)

GScom has developed the symbol synchronization and frame synchronization technologies using a preamble sequence in the acquisition frame, and symbol tracking and frame time tracking using a time Delay Locked Loop (DLL) with the 2^{nd} order Phase Locked Loop (PLL).

◆ ACM (Adaptive Coding & Modulation)

ACM is a communication technology which is used to maximize the communication system efficiency with a given channel condition. GScom has developed an ACM technology which uses real-time channel information of the SNR from the equalizer, RSSI from the AGC, and desired range of SNR in the modulation and coding technology. The ACM supports 4-QAM, 16-QAM, 64-QAM, 256-QAM, 1024-QAM, and 4096-QAM modulation rates. The ACM also supports any error correcting R-S code and LDPC code rates of 0.5 and 0.75.

4.3 Technology Consulting Service

GScom has been working on a wireless backhaul modem and its core technology development over the past three years and has developed a complete wireless backhaul 4096-QAM modem for Gigabit communication.

Each of the founding members of GScom has a minimum of twenty five years of experience working in the wireless communications area for tier-1 wireless communication companies including Nokia, Sony, Samsung, Via Telecom, Infineon, Broadcom and Xilinx.

GScom has a broad background, experience, and expertise in wireless communication system analysis, system design, algorithm design, system partitioning and hardware optimization. The GScom team has a broad spectrum of development experience in the development of a variety of wireless communication baseband system, such as IS-54, HSDPA, HSUPA, LTE, 802.11n, 802.11ac, along with broadband backhaul communication systems. GScom provides consulting services for technology development not only at the systems level but also at the hardware implementation level.

GScom provides technical development and consulting services in the following areas:

1. Product development of wireless communication baseband modems for handset and/or backhaul communication systems.
2. Core component wireless technology development for handset and/or backhaul communication systems.
3. Hardware system development and optimization of the wireless communication technology for handset and/or backhaul communication systems.

5 References

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