Choosing Optimum Noise Figure and Data Rate in Wireless Sensor Network Radio Transceivers

R. Dutta, R. v. d. Zee, M. J. Bentum and A. B. J. Kokkeler

University of Twente, Enschede, The Netherlands

email: R.dutta@utwente.nl, R.A.R.vanderZee@utwente.nl, M.J.Bentum@utwente.nl, A.B.J.Kokkeler@utwente.nl

Abstract— To reduce the energy consumption in wireless sensor network transceivers, we propose an approach which combines two tradeoffs. The first tradeoff is between the receiver sensitivity and transmitter output power. The second one is the duty cycle and data rate of the transceiver. The combined approach gives us the optimum choice of noise figure and data rate for a given application and transceiver architecture. Considering a typical transceiver architecture and perfectly synchronized system, we show that the energy consumption can indeed be reduced with this approach compared to choosing either data rate or noise figure arbitrarily. Moreover, in case of a wakeup receiver architecture and slot based MAC protocol, applying this method, we show that there is a different combination of optimum data rate and noise figure value for the wakeup receivers to minimize the wakeup energy.

Index terms- Energy, wireless sensor network, noise figure, data rate, duty-cycled radio.

I. INTRODUCTION

Most applications of wireless sensor networks (WSNs) desire an ultra low power radio to extend the battery life [1-2], so that no or minimum extra maintenance is required after initial installation. With the advanced scaling in CMOS technology, power consumption of processors and semiconductor memories has reduced drastically. Therefore, the radio transceiver is the bottleneck to extend battery lifetime of sensor nodes [3-5]. Thus, energy reduction in a robust radio communication system is one of the major challenges in recent WSN transceiver designs.

To reduce a significant amount of energy dissipation, various approaches have been adopted at each layer of the communication system design. In the physical layer, transceiver system design also needs to be optimized to reduce the energy consumption. This approach differs from the conventional transceiver system design where more importance is given to system performance (high data rate, bandwidth efficiency) rather than energy consumption.

One general optimization approach is to choose the transmitter (TX) output power to minimize the total power consumption in the transceiver system. Optimum TX power is required because very high radiated power will increase the TX power considerably more than the power reduction achieved by exploiting worse sensitivity at the receiver (RX). On the other hand, at very low TX radiated power, the RX will consume much more power to increase its sensitivity. So, there is an optimum level of TX output power, which will minimize the total transceiver power consumption. For a given bandwidth

Figure 1. Simplified block diagram of a typical transceiver

and signal to noise ratio (SNR) requirement in a RX, the RX noise figure (NF) determines the RX sensitivity. Then the NF determines the TX output power level for a given link budget. Therefore there is an optimum NF corresponding to the minimum total power.

Duty-cycling the radio transceiver is an effective way to reduce the energy consumption [6] in a radio communication system. In a duty-cycled radio, there is another tradeoff between duty cycle and data rate (DR) [5][7][8]. The tradeoff shown in these references suggests an optimum DR, assuming fixed RX sensitivity. However, fixing the sensitivity will restrict to achieve the overall minimum energy. Here we optimize for DR and NF together without the sensitivity restriction which reduces energy compared to the previous approaches. This optimization will differ depending on the rendez-vous scheme [9] used. To prove the energy reduction, we apply this approach to two rendez-vous schemes; a synchronous scheme and a pseudo-asynchronous scheme. The example of the pseudo-asynchronous scheme is taken from a slot based MAC protocol [10] proposed for a wakeup radio.

In Section II, we discuss the NF optimization of a non-duty cycled (always ON) radio and in Section III, we discuss the data rate and duty cycle tradeoff in duty cycled radio as previously reported. In Section IV, we propose energy reduction by choosing the optimum NF and DR for a duty cycled synchronous transceiver. In Section V, we apply the proposed approach to optimize the wakeup radio energy for a slot based MAC protocol used in a wakeup radio. After discussions in Section VI, the conclusions are presented in Section VII.

II. OPTIMUM NOISE FIGURE FOR NON-DUTY CYCLED RADIO

The total transceiver power consumption can be written as,

$$P_T = P_{RX} + \frac{P_{RAD}}{\eta} \quad (1)$$

Figure 2. A typical RX architecture where RX NF is dominated by LNA NF.

where P_{RX} = RX power consumption, P_{RAD} = TX output power and η = TX efficiency which is defined as the ratio of transmitted power and TX total power consumption. The noise contribution and power consumption can be traded off in the RX blocks, such as mixer, low noise amplifier (LNA) etc. [11]. Typically in a RX frontend, as shown in Figure 2, the LNA amplifies the RF signal such that the effect of the rest of the blocks on the RX NF is not very significant. We assume the RX NF is dominated by the LNA NF similar to [12]. Considering a widely used common source LNA, the noise factor and the LNA power can be related as [12],

$$F = F_L = 1 + \frac{K_L}{P_L} \quad (2)$$

where F is the RX noise factor, F_L and P_L are the LNA noise factor and the power consumption respectively, K_L is a design constant, expressed in watt (required power consumption to achieve $F = 2$) which depends on the gain, IIP3, the LNA configuration, technology, etc. Here we tradeoff between noise and power consumption and assume other performance parameters are kept fixed (such as IIP3, gain of the LNA etc.). In other words, we assume that an LNA can be designed to achieve a fixed 'figure of merit' [$FoM1$ and $FoM2$ in 14] even though we tradeoff power consumption and the NF. We used noise factor (F) instead of NF ($NF = 10 \log_{10}(F)$) for simplification of the calculation, although we specify and discuss about the NF as it is commonly used as a specification.

The rest of the power consumption in the RX, other than LNA, is independent of the RX NF. Therefore, the total RX power consumption can be approximated as,

$$P_{RX} = P_{Rf} + \frac{K_L}{F-1} \quad (3)$$

where P_{Rf} is power consumption of the blocks independent of the RX NF. The TX radiated power is [13]:

$$P_{rad} = \frac{SNR \cdot kT \cdot LB \cdot F \cdot B}{G_t \cdot G_r} \quad (4)$$

where SNR is signal to noise ratio required in the RX, G_t is the TX antenna gain, G_r is the RX antenna gain, B is the (noise) bandwidth and LB is the link budget. The upper link budget is fixed for a given distance and channel property, considering worst case effects. In this scenario, $SNR \cdot kT \cdot LB$ can be assumed to be a constant K_R as SNR is specified by the demodulator and LB is specified by the application. Therefore, the TX power consumption can be modeled as:

$$P_{TX} = P_{Tf} + \frac{K_R \cdot F \cdot B}{\eta \cdot G_t \cdot G_r} \quad (5)$$

TABLE I: LIST OF DESIGN SPECIFICATION IN A GIVEN SCENARIO

Parameter	Value	Unit
Frequency (ISM band)	2.45	GHz
Link budget (LB)	60	dB
Signal to noise ratio (SNR)	7	dB
Bandwidth efficiency (K_b)	1	bits/second/Hz
TX efficiency (η)	50	%
Number of bits per packet.	100	-
Startup time (t_s)	250	μ s
Fixed RX power	0.5	mW
Fixed TX power	0.5	mW

Figure 3. Receiver, transmitter and total power with respect to Noise Figure.

where P_{Tf} is fixed TX power consumption independent of the radiated power like the oscillator power consumption. Let us assume the antenna gains are close to unity. Therefore the total power ($P_{TX} + P_{RX}$) in term of the NF, can be written as,

$$P_T = P_{Rf} + P_{Tf} + \frac{K_L}{F-1} + \frac{K_R \cdot F \cdot B}{\eta} \quad (6)$$

Note that with increasing noise factor, F , the RX power consumption decreases but the TX power increases. So, there is an optimum NF. We obtain:

$$\frac{\partial P_T}{\partial F} = 0 \Rightarrow F_{OPT} = 1 + \sqrt{\frac{\eta \cdot K_L}{K_R \cdot B}} \quad (7)$$

The constant K_L can be estimated from equation (2). As an example, we choose an LNA [14] which achieves NF of 2 dB (i.e. noise factor, $F = 1.58$) and power consumption of 2.6 mW in a 0.13 μ m technology. Using these values in (2), we obtain $K_L = 1.52 \times 10^{-3}$ watt. Note that K_L can vary largely with the LNA gain, linearity, technology, frequency of operation etc. For a given scenario with the values listed in Table 1 and for a DR of 100 kbps, an optimum NF of 14 dB is obtained using (7). The change of RX power, TX power and the total power with respect to the NF is plotted in Figure 3. It shows that indeed there is an optimum NF which minimizes the total power consumption. Note that, this optimum is at one specific DR chosen arbitrarily as 100 kbps.

III. DATA RATE AND DUTY CYCLE TRADEOFF FOR A GIVEN RECEIVER SENSITIVITY

In transceivers, power consumption reduces with decreasing DR because the baseband circuits operate at a reduced frequency [14] and noise bandwidth is less for a given spectral efficiency. However, for a duty-cycled radio, a higher

DR corresponds to faster transmission and less transceiver ON time for a fixed number bit transmissions. Clearly, there is a tradeoff between the DR and duty cycling. Here by DR we mean DR during ON time. This tradeoff has been shown in [6-8]. In this section, we incorporate this approach to the total transceiver energy instead of only the RX energy.

For a fixed sensitivity requirement, if the DR increases, NF has to be improved to compensate the increase in the noise bandwidth. So, if the spectral efficiency is unchanged, the DR is proportional to the bandwidth and hence inversely proportional to the required noise factor, F . Therefore,

$$F = \frac{K_{FD}}{R} \quad (9)$$

where, R is the DR in bps, K_{FD} is a design constant, expressed in bps. It can be calculated using a known combination of F and R . The transceiver ON time can be multiplied with (6) to get the total transceiver energy as:

$$E_T = \left(P_{Rf} + \frac{K_L \cdot R}{K_{FD} - R} + P_{TX} \right) \left(\frac{N_b}{R} \right) \quad (10)$$

where P_{TX} is fixed as the sensitivity is fixed in this case, N_b is the number of bits to be transferred. We assume the ON times of the RX and the TX are the same; assuming a perfectly synchronous system. To minimize the energy consumption, we do:

$$\frac{\partial E_T}{\partial R} = 0 \Rightarrow R_{opt} = K_{FD} \left(1 + \sqrt{\frac{K_L}{P_{Rf} + P_{TX}}} \right)^{-1} \quad (11)$$

As an example, if $K_{FD} = 10$ Mbps (20 dB of NF is acceptable for DR of 100 kbps for an achievable sensitivity of -97 dBm) then we get $R_{opt} = 4.5$ Mbps by (11) and corresponding $NF = 3.5$ by (9). Clearly, optimum data rate changes with K_{FD} which changes with the RX sensitivity and the choice of NF and DR in calculating K_{FD} . Therefore this approach has to be improved to minimize transceiver energy.

IV. OPTIMUM DATA RATE AND NOISE FIGURE FOR DUTY-CYCLED RADIO COMMUNICATION

As we have seen in Section II that the RX sensitivity can be traded off with the TX output power to minimize overall power consumption. So to minimize energy we need to remove the fixed RX sensitivity assumption in Section III and combine the two tradeoffs discussed in Sections II and III.

In this section we optimize transceiver DR and RX NF together for a given application (link budget, operating frequency specified) and given architecture (SNR, topology of front end, technology, TX efficiency specified). These two parameters are very influential in a transceiver system because RX sensitivity and TX output power can be deduced from DR and NF. In this case, (9) will not be valid because the RX sensitivity is no longer fixed.

The energy consumed in the transceiver to transfer one packet can be modeled from (6) as:

$$E_T = \frac{N_b}{R} \left(P_{Rf} + P_{Tf} + \frac{K_L}{F-1} + \frac{K_R \cdot B \cdot F}{\eta} \right) \quad (12)$$

The baseband power consumption, till now assumed under the fixed power in receiver and transmitter, changes with the DR.

TABLE II: MINIMUM ENERGY AT VARIOUS NF AND DATA RATE

Parameter	Optimized NF (Section II)	Optimized DR (Section III)	Proposed approach NF- R optimized	Unit
	Choose R	Choose K_{FD}		
Data-rate	100 k	4.5 M	1.2 M	bps
NF	14	3.5	8	dB
TX Power	-43	-37	-38	dBm
RX Sensitivity	-103	-97	-98	dBm
Transceiver Energy	1466	837	573	nJ

Figure 4. Transceiver energy (in nJ) with receiver noise figure and data rate

The fixed power in (12), i.e. $(P_{Rf} + P_{Tf})$ has to be modified to take that into consideration. The RX and TX will take some startup time to be ready to operate. Again we assume here a perfectly synchronous system which means both RX and TX are ON only for the required transmission time. In practice, the TX may initiate the communication and wait for the RX to turn ON for a considerable amount of time. Or the RX may be ON periodically to check for any input signal. We will look into that in the next section. The startup time is dominated by the clock generator such as a phase lock-loop (PLL) startup time, and is typically similar in value for the RX and the TX [15]. Although the power consumption in startup can be less than the operating power consumption, for a worst case analysis we assume the startup power consumption is the same as during the operating time. As bandwidth is proportional to the DR for a given spectral efficiency we can modify (12) accordingly and arrive at:

$$E_T = \left(\frac{N_b}{R} + t_s \right) \left(P_F + R \cdot P_B + \frac{K_L}{F-1} + \frac{K_R \cdot K_b \cdot R \cdot F}{\eta} \right) \quad (13)$$

where t_s is the RX/TX startup time, P_F is the total power consumption independent of the NF and DR, P_B is the baseband power consumption per unit DR frequency (Watt/Hz) and K_b is the ratio between bandwidth and DR. Here we assume, 1) The RX and the TX are only active for the time required for the transmission of one packet. 2) The power consumption of the RX and the TX while sleeping is negligible. 3) The data propagation time is considered negligible compared to the bit period.

Let us assume a scenario with values as shown in Table I and chosen P_B is 10^{-4} μ W/Hz i.e. baseband power consumption of 100 μ W at 1 Mbps. The total energy consumption for one packet transmission at various DRs and

Figure 5. Optimum NF and DR as startup time changes

Figure 6. Optimum NF and DR as link budget changes

NFs is plotted in Figure 4. It shows that indeed there is an optimum DR and NF for this given scenario. The optimum NF is 8dB and optimum DR is 1.2 Mb. Table II compares this result with two other approaches. In one case, the DR is arbitrarily chosen and NF is optimized by (7), i.e. the approach in Section II, and in the other case, the DR is optimized by (11), i.e. the approach in Section III. The transceiver energy found by (13) in all those approaches are larger than the optimum we obtained.

1) Boundary conditions of the optimum

There are some boundary conditions which have to be satisfied to make this approach successful. Although the plot shows a wide range of DR and NF values, not all of these combinations are acceptable in practice. The DR has to be restricted to a range from the basic DR required by the application to a value which supports the available channel bandwidth and modulation scheme. The boundary of the NF is determined by the technology, RX circuit topology, design and chip area etc. The power consumption and NF tradeoff approximated in (2) may change outside a boundary. Another factor is the battery efficiency which gets degraded for very high DR as the instantaneous power is very high, even if the overall energy is low. The requirement of an impractically larger capacitor [16] puts a limit to the high DR value.

2) Optimum With Varing Design Specifications

In this sub-section we determine how the optimum value of the NF and the DR changes if the specifications and design parameters change. The optimum value of NF and the DR change as a function of startup time and link budget, as shown Figure 5 and Figure 6 respectively. For example if the startup time of the system improves, the system has to be changed to a different optimum to achieve minimum energy.

Figure 7. Wakeup energy (in nJ) with receiver noise figure and data rate

TABLE III: MINIMUM ENERGY AT VARIOUS NF AND DATA RATE

Parameter	Value	Unit
Bandwidth efficiency (K_b)	1	-
Packet rate	1	/minute
Number of wakeup bits	100	-
Startup time (t_{sw})	250	μ s
Fixed WuRX power	0.5	mW

From Figure 6, we observe that the optimum DR and NF both reduce with increasing requirements of the link budget. Note that the effect of a changed SNR requirement also can be predicted from the Figure 6 as SNR and link budget affect (13) similarly. For example decreasing the link budget by 3dB will have a similar effect as decreasing the required SNR by 3dB or increasing TX efficiency by two times.

V. OPTIMUM DATA RATE AND NOISE FIGURE FOR WAKEUP RADIO FOR A SLOT BASED MAC PROTOCOL

A wakeup radio RX architecture consists of an extra separate RX (called the wakeup-receiver) to wakeup the main receiver when required [17]. The overall energy consumption can be reduced assuming an ultra low power wakeup receiver (WuRX) is available [18]. It is clear that the ON time for this WuRX is different to the main RX. Therefore, we claim that there is a different optimum DR and NF for a WuRX and main RX. In fact this is one of the most effective ways wakeup radio power consumption can be reduced. We show this for a slot-based MAC protocol for a WuRX proposed by [10].

In [10], the WuRX is also duty cycled and tuned ON periodically to sense the channel. The main RX is only ON for the time required to receive the data. To synchronize the clocks of the sensor nodes, a "sync beacon" signal is sent periodically (called beacon period) to correct the clock error among the sensor nodes. If the clock edge error is a fraction $\pm e_{clk}$ fraction of the clock period, the maximum time uncertainty of a clock phase between the TX and the RX is $2(e_{clk} / R_B)$, where beacon rate = R_B . The wakeup radio has to operate for this extra time so that the error can be tolerated. The total energy consumption in 'wakeup' is the addition of the energy consumed in the WuRX and the energy consumed in the TX sending the wakeup bits. We modify (13) accordingly to get the total wakeup energy as:

TABLE IV: MINIMUM ENERGY OF WAKEUP RECEIVER FOR DIFFERENT CLOCK ACCURACY

Parameter	Case 1	Case 2	Case 3	Unit
Clock inaccuracy	10000	1000	100	ppm
Beacon rate (R_B)	0.2	0.09	0.03	Hz
Wakeup NF	24	22	18	dB
Wakeup DR	250k	500k	900k	bps
TX output power	1	2	0	dBm
Wakeup energy	22370	2542	355	nJ

$$E_W = \left(\frac{4e_{clk}}{R_B} + \frac{N_W}{R_W} + t_{SW} \right) \left(\frac{K_L}{F_W - 1} + P_{Rf} + R_W \cdot P_{WB} \right) + \frac{N_W}{R_W} \left(\frac{K_R \cdot K_b \cdot R_W \cdot F_W}{\eta} + P_{Tf} \right) \quad (16)$$

where t_{SW} is the wakeup radio startup time, subscript W specifies the parameters for wakeup radio, F_W is the noise factor of the wakeup radio, R_W is the DR of the wakeup radio, P_{WB} is the baseband power constant of the WuRX, N_W is the number of bits required to transmit to wakeup the main radio (RX) of a specific sensor node.

Equation (16) is used to deduce the optimized NF and DR for our application specified in Table III and the chosen P_{WB} is 10^{-5} μ W/Hz i.e. 10 μ W at 1 Mbps. Table IV shows the wakeup energy at the optimum DR and NF for three different clock inaccuracies. Table IV also shows the optimum beacon rates corresponding to those clock inaccuracies, taken from [10]. The total energy at various values of DR and NF is plotted in Figure 7 for clock accuracy of 100ppm. Other specifications and constants are the same as in Table I. As the WuRX is ON for a longer time, it is expected to have a larger optimum TX power and worse RX sensitivity to minimize RX power. Thus, despite having the same link budget and architecture, the WuRX power consumption can be lower than the main receiver; supporting the basic WuRX assumption.

VI. DISCUSSION

A different optimum DR in the WuRX and the main RX minimizes the overall energy consumption. However, there are some consequences using different DR and NF for those two RXs. At the wakeup of the main RX, the TX has to switch from transmitting wakeup bits at one DR to data bits at a different DR. At the time when the main RX is switching ON, because of low DR of the WuRX, it may switch ON the main RX at an incorrect time instant. The time error can be as large as the WuRX bit period. For correct operations, the WuRX has to switch ON the main RX at least one wakeup bit period before receiving the actual data; to guarantee that the main radio wakes up before actual data is reached. The TX power has to be changed from wakeup bit to actual data transmission.

VII. CONCLUSION

To minimize the energy consumption of a wireless sensor network transceiver, an approach is described where we choose the optimum RX noise figure and data rate. We show that there is an optimum combination of NF and DR which minimizes the overall transceiver energy. Rather than choosing a predefined value from intuition, this approach can lead to a significant reduction of the energy consumption for a

given application, MAC protocol and receiver structure. Moreover, this approach can be used to reduce wakeup energy, and shows an effective way to reduce the WuRX power consumption compared to main receiver. Power reduction possible in WuRX in this way will give more support for the wakeup radio architectures in wireless sensor network.

REFERENCES

- [1] Akyildiz I.F., Su W., Sankarasubramaniam Y., Cayirci E. "A survey on sensor networks," *IEEE Communications Magazine*, 40 (8), pp. 102-105, 2002.
- [2] Schwiebert L., Gupta S.K.S., Weinmann J. "Research challenges in wireless networks of biomedical sensors," *Proceedings of the Annual International Conference on Mobile Computing and Networking, MOBICOM*, pp. 151-165, 2001.
- [3] Perkins M., Correal N., O'Dea B. "Emergent Wireless Sensor Network limitations: A plea for advancement in core Technologies," *Proceedings of IEEE Sensors*, 1 (2), pp. 1505-1509, 2002.
- [4] Ben W. Cook, Axel Berny, Alyosha Molnar, Steven Lanzisera, and Kristofer S. J. Pister, "Low-Power 2.4-GHz Transceiver With Passive RX Front-End and 400-mV Supply," *IEEE J. of solid state circuit*, vol. 41, no. 12, pp. 2757-2766, 2006.
- [5] B. W. Cook, S. Lanzisera, K. S. J. Pister, "SoC issues for RF smart dust," *Proceedings of the IEEE*, 94 (6), pp. 1177-1195, 2006.
- [6] Rabaey, J. M., J. Ammer, et al. (2002). PicoRadios for wireless sensor networks: The next challenge in ultra-low power design," *Digest of Technical Papers - IEEE International Solid-State Circuits Conference*, San Francisco, CA.
- [7] C. C. Enz, N. Scolari, and U. Yodprasit, "Ultra low-power radio design for wireless sensor networks," in *Proc. IEEE Int. Workshop Radio-Frequency Integration Technol.*, Nov. 2005, pp. 1-17.
- [8] A.-S. Porret, "Design of a Low-Power and Low-Voltage UHF Transceiver Integrated in a CMOS Process," Ph.D. dissertation, Swiss Federal Institute of Technology, Lausanne (EPFL), 2002.
- [9] Lin E.-Y.A., Rabaey J.M. and Wolisz A. "Power-efficient Rendez-vous schemes for dense wireless sensor networks," *IEEE International Conference on Communications*, 7, pp. 3769-3776, 2004.
- [10] Salvatore Drago, Fabio Sebastiano, Lucien J. Breems, Domine M.W. Leenaerts, Kofi A. A. Makinwa and Bram Nauta, "Impulse-Based Scheme for Crystal-Less ULP Radios," *IEEE Trans. on Circuits and Systems—I: Regular Papers*, vol. 56, no. 5, May 2009.
- [11] E. A. M. Klumperink and B. Nauta, "Systematic comparison of HF CMOS transconductors," *IEEE Trans. Circuits Syst. II, Analog Digit. Signal Process.*, vol. 50, no. 10, pp. 728-741, Oct. 2003.
- [12] Cook, B.W.; Molnar, A. Pister, K.S.J. "Low Power RF Design for Sensor Networks", *Radio Frequency integrated Circuits (RFIC) Symposium*, 2005. Digest of Papers. 2005 IEEE.
- [13] B. Razavi, *RF Microelectronics*. Englewood Cliffs, NJ: Prentice-Hall 1998.
- [14] S. Joo, T. Y. Choi, B. Jung, "A 2.4-GHz resistive feedback LNA in 0.13 μ m CMOS," *IEEE J. of solid state circuit*, vol. 44, no. 12, pp. 2757-2766, Nov., 2006.
- [15] Datasheet from Chipcon (TI), CC2420, "Single-Chip 2.4 GHz IEEE 802.15.4 Compliant and ZigBee™ Ready RF Transceiver," <http://focus.ti.com/docs/prod/folders/print/cc2420.html>.
- [16] M. Pedram and Q. Wu, "Design considerations for battery powered electronics," in *Proc. 36th ACM/IEEE conf. Design Automation (DAC '99)*, jun. 1999, pp.861-866.
- [17] Ilker Demirkol, Cem Eesoy, Bogazici, Ertan Onur, "Wake-up Receivers for wireless sensor networks: Benefits and challenges," *IEEE Wireless Communication*, Aug. 2009.
- [18] Pletcher, N. M., S. Gambini, et al. (2009). "A 52 μ W Wake-Up receiver with -72 dBm sensitivity using an uncertain-IF architecture." *IEEE J. of Solid-State Circuits*, vol 44, no 1, pp 269-280, 2009.