UNIVERSITI PUTRA MALAYSIA

ENERGY BALANCING MECHANISMS FOR DECENTRALIZED ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORKS

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By

AHMED MOHAMMED SHAMSAN SALEH

Thesis Submitted to the School Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATIONS

To my late father Mohammed Shamsan,

To my late mother Shafiqah,

To my lovely wife Enas,

To my brothers, my sisters, and my wonderful Kids.

Abstract of thesis presented to the Senate of University Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Faculty: Engineering

In Wireless Sensor Networks (WSNs), the sudden "death" of critical nodes can cause an entire network to malfunction. This is usually caused by uneven depletion of battery power of the individual nodes. In an unbalanced network, while critical nodes experience heavy traffic load which depletes their energy fast and die out, nodes in sparse regions in terms of data traffic continue to enjoy high energy levels. Therefore, this thesis investigates a method to balance and minimize usage of energy in sensor nodes, especially during routing. This is because network activities start to be challenged when the first sensor node exhausts its battery. Hence the proposed routing protocols in this thesis balances the rate of energy dissipation of the sensor nodes across the network and prevents sensor nodes from directly transmitting to far-off nodes, in most cases, when forwarding data to the sink, as this will cost unnecessarily high-energy expense. Thus, our main goal in this thesis is to develop a decentralized energy balancing and

locally managed schemes to prolong the lifetime of WSNs and increase its reliability to network dynamics. This thesis presents three decentralized algorithms that are robust, scalable, and can be successfully executed in sensor networks. The first scheme is a SensorAnt, which is a self-optimization mechanism for WSN. It is able to utilize and optimize the sensor nodes' resources, especially the batteries, to achieve balanced energy consumption across all sensor nodes. It is based on Ant Colony Optimization (ACO) meta heuristic, which is adopted to enhance the paths with the best-quality function. The assessment of this function depends on multi-criteria metrics such as the minimum residual battery power, hop count, average energy of the route and average energy of the network. The second one is a Reliable Routing Scheme for Energy-Balancing (RRSEB), which is a self-adaptive scheme to ensure the high routing reliability in WSNs, if the failures occur due to the movement of the sensor nodes or due to sensor node's energy depletion. The RRSEB operations focus on enhancement of the path recovery process, this is done by introducing proactively route mechanism to create alternative paths together with the data routing obtained by path discovery stage in order to reduce the packet drops. The goal of these operations is to update and offer new routing information in order to construct the multiple paths resulting in an increased reliability of the system. Finally, we propose Self-Decision Route Selection scheme which is an improvement of the Hop-based Spanning Tree (HST) algorithm that is used in some routing protocols such as AODV and DSR. This scheme utilizes the control packets of HST to advertise the residual energies of the sensors to their respective neighbors in order to make a self-decision routing. By this means sensor nodes transmit the data either to next hop neighbors or directly to the sink node. This load balancing scheme distributes the traffic load regularly and slowly over the sensor nodes during

routing, such that the overall network life time is optimized, and the sensors die almost at the same time.

The performance of the proposed algorithms has been studied through simulations and a significant improvement in terms of energy consumption, energy efficiency, energy balancing and packet delivery ratio has been achieved. SensorAnt shows superior performance compared to Energy Efficient Ant Based Routing (EEABR). It reduces total energy consumption by 71%, while performance improves by 76% in terms of energy-efficiency. Whereas the RRSEB reduces the packet drops by up to 54% and the energy efficiency improves by up to 22%. Finally, the proposed Self-decision Route Selection scheme reduces the transmission energy usage by up to 64%, while the reception energy usage is reduces by up to 67%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

MEKANISMA PENGIMBANGAN TENAGA UNTUK PROTOKOL LALUAN TERAGIH DALAM RANGKAIAN PENGESAN TANPA WAYAR

Oleh

AHMED MOHAMMED SHAMSAN SALEH

November 2012

Pengerusi: Professor Borhanuddin Mohd Ali, PhD

Fakulti: Kejuruteraan

Di dalam sistem rangkaian pengesan tanpa wayar (*Wireless Sensor Networks, WSNs*), nod kritikal yang tidak berfungsi secara tiba-tiba boleh menyebabkan gangguan terhadap seluruh rangkaian *WSN*. Masalah ini berlaku akibat daripada pengurangan kuasa bateri oleh nod individu. Di dalam sistem rangkaian yang tidak seimbang, ketika nod kritikal mengalami beban trafik yang tinggi yang juga telah mengurangkan tenaga secara pantas, nod yang berada di kawasan yang tidak padat dari segi trafik data terus menggunakan tenaga pada kadar yang tinggi. Oleh yang sedemikian, tesis ini dilaksanakan bagi mengkaji kaedah untuk mengimbangkan dan mengurangkan penggunaan tenaga di dalam nod pengesan (*sensor node*), terutamanya ketika proses penghalaan laluan (*routing*). Cabaran bagi rangkaian *WSN* bermula ketika nod pengesan pertama kehabisan tenaga bateri. Berdasarkan cabaran tersebut, tesis ini mencadangkan satu kaedah penghalaan laluan (*routing*) dengan mengimbangkan kadar kehilangan tenaga oleh nod pengesan sepanjang rangkaian *WSN*. Selain itu, cadangan bagi kaedah penghalaan laluan

ini juga dicipta untuk mengelak nod pengesan daripada menghantar isyarat ke nod yang jauh kerana ini boleh meyebabkan pembaziran penggunaan tenaga yang tinggi. Matlamat utama tesis ini adalah untuk menghasilkan rangkaian pengimbang tenaga secara teragih dan kaedah pengurusan tersendiri untuk memanjangkan jangka hayat *WSNs* dan meningkatkan keutuhannya ke rangkaian dinamik. Tesis ini membincangkan tiga algoritma teragih yang teguh, berskala dan boleh dilaksanakan dalam di dalam rangkaian *WSN*. Algoritma yang pertama ialah *SensorAnt*, dimana sistem ini menggunakan mekanisma pengoptimuman tersendiri (*Self-optimization*) bagi *WSN*. Kaedah ini mampu untuk mengoptimumkan sumber nod pengesan, terutamanya bateri, untuk mencapai keseimbangan penggunaan tenaga ke atas semua nod pengesan. *SensorAnt* dihasilkan berdasarkan *Ant Colony Optimization (ACO) meta heuristic* yang digunakan untuk menambahbaik laluan dengan fungsi kualiti yang terbaik. Penilaian terhadap fungsi ini bergantung kepada beberapa kriteria antaranya, sisa kuasa bateri yang minimum, kiraan lompatan (*Hop count*), purata tenaga bagi laluan (*average energy to route*) dan purata tenaga bagi rangkaian (*average energy to network*). Algoritma kedua pula dicipta bagi memastikan penghalaan laluan yang lebih dipercayai (*High routing reliability*) dalam rangkaian *WSNs* apabila rangkaian *WSNs* gagal berfungsi akibat dari pergerakan nod pengesan atau kekurangan tenaga dari nod pengesan. Kaedah ini dikenali sebagai *Reliable Routing Scheme for Energy-Balancing (RRSEB). RRSEB* lebih fokus kepada penambahbaikan dalam proses pemulihan laluan (*Path Recovery*) dengan memperkenalkan mekanisma laluan secara proaktif untuk membentuk laluan alternatif dengan menggunakan maklumat penghalaan laluan yang telah diperolehi pada peringkat pencarian laluan (*path discovery)* untuk mengurangkan kehilangan paket yang dihantar. Matlamat algoritma *RRSEB* adalah untuk mengemas kini dan menawarkan

maklumat penghalaan laluan yang baru bagi membentuk pelbagai laluan yang dapat meningkatkan kebolehpercayaan sistem ini. Algoritma terakhir yang dicadangkan ialah *Self-Decision Route Selection*, dimana kaedah ini merupakan satu teknik penambahbaikkan terhadap algoritma *Hop-based Spanning tree (HST)* yang digunakan dalam beberapa protokol penghalaan laluan seperti AODV dan DSR. Skim ini menggunakan paket kawalan HST untuk mengiklankan tenaga sisa (*residual energies*) pengesan kepada jiran (*neighbors*) masing-masing untuk membuat keputusan pemilihan penghalaan laluan sendiri. Ini bermakna, nod pengesan menghantar data sama ada kepada jiran sebelah (*Next Hop Neighbors*) atau secara terus ke nod penerima (*Sink node*). Skim pengimbang beban ini mengagihkan beban trafik secara kerap dan secara perlahan ke seluruh nod pengesan semasa penghalaan laluan, dimana keseluruhan masa rangkaian dioptimumkan dan nod–nod pengesan gagal berfungsi pada waktu yang sama.

Prestasi algoritma yang dicadangkan telah dikaji menerusi simulasi dan peningkatan yang ketara dari segi penggunaan tenaga (*energy consumption*), kecekapan tenaga (*energy efficiency*), keseimbangan tenaga (*energy balancing*) dan nisbah paket penghantaran (*packet delivery ratio*) yang telah dicapai. *SensorAnt* menunjukkan prestasi unggul berbanding dengan EEABR. Ia mengurangkan jumlah penggunaan tenaga sebanyak 71%, manakala prestasi bertambah baik sebanyak 76% dari segi kecekapan tenaga. Manakala RRSEB mengurangkan kehilangan paket (*packet drop*) sehingga 54% dan kecekapan tenaga meningkat sehingga 22%. Secara kesimpulannya, cadangan bagi *Self-Decision Route Selection* mengurangkan penggunaan penghantaran tenaga sehingga 64%, manakala penerimaan penggunaan tenaga dikurangkan sehingga 67%.

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I certify that a Thesis Examination Committee has met on 30 November 2012 to conduct the final examination of Ahmed Mohammed Shamsan Saleh on his Doctor of Philosophy thesis entitled "Energy Balancing Mechanisms for Decentralized Routing Protocols in Wireless Sensor Networks" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the University Putra Malaysia [P. U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Doctor of Philosophy

Members of the Thesis Examination Committee were as follows:

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This thesis was submitted to the Senate of University Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at University Putra Malaysia or at any other institution.

AHMED MOHAMMED SHAMSAN SALEH

Date: 30 November 2012

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