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Energy Performance in Wireless Sensor Network

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Abstract

Wireless sensor networks are becoming very popular technology, it is very important to understand the architecture and energy consumption for this kind of networks before deploying it in any application. This paper explores the wireless sensor networks (WSN) in energy performance in order to achieve good background on the wireless sensor networks and help readers to find a more details on these ideas.

1. Introduction

WSN initially consists of small or large nodes called as sensor nodes. These nodes are varying in size and totally depend on the size because different sizes of sensor nodes work efficiently in different fields. Wireless sensor networking have such sensor nodes which are specially designed in such a typical way that they have a microcontroller which controls the monitoring, a radio transceiver for generating radio waves, different type of wireless communicating devices and also equipped with an energy source such as battery. The entire network worked simultaneously by using different dimensions of sensors and worked on the phenomenon of multi routing algorithm which is also termed as wireless ad hoc networking. Each node has one or more sensors integrated on it. In addition to these sensors, a node is also equipped with a transmitter and a receiver. These transmitter and receiver are used for wireless communications with other nodes or directly with the gateway. The gateway is responsible for transmitting sensor data from the sensor patch to the remote base station that provides Wireless Ad-Hoc Network (**WANET**) connectivity and data logging through a local transit network. Finally, the data is available to researchers through a user interface. The scenario of Wireless Sensor Network is shown in figure 1 [1, 2]..

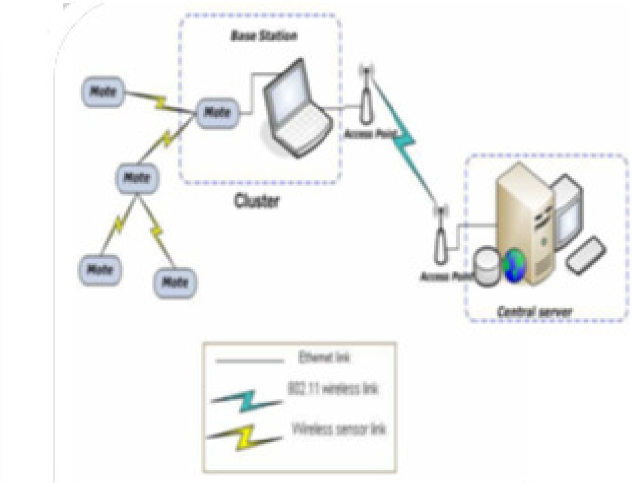

figure (1): The scenario of Wireless Sensor Network

2. What is the Sensor Network?

A sensor network is a collection of communicating sensing devices. These devices communicate wirelessly to transmit their readings and widely known as wireless sensors. A sensor network is collection of such communicating devices. When large number of sensors can be spread across a geographical area and networked in applications then it is termed as Wireless sensor Network. Clustering is a technique that is used to enhance the lifetime of the sensor network by reducing energy consumption. This paper provides experimental performance in energy consuming for wireless sensor network. This paper considers the following protocols that organize sensor network into energy efficient algorithm for simulation studies. i.e. sensor nodes form clusters where the low energy nodes are used to perform the sensing in the proximity of the phenomenon. The less energy constrained nodes play the role of cluster-heads and process, aggregate and forward the information to a potential layer of clusters among themselves toward the base station. In this section, as in figure 2 below it introduces three cluster based scheduling mechanism.

- **Leach** (Low-energy adaptive clustering hierarchy)
- **SEP** (Stable Election Protocol)
- **TEEN** (Threshold sensitive energy efficient sensor network protocol)

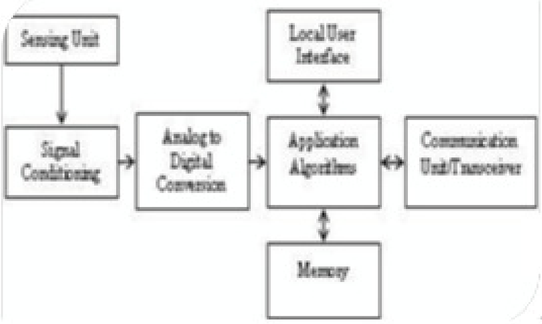

Figure (2): three cluster based scheduling mechanism

3. WSN and Other Wireless Technologies

Wireless communication technologies are categorized based on their typical coverage and application domains. The link range, data rate, mobility, and power requirements of the technologies are presented in figure 3 The values are not definite but illustrate the differences between the technologies. In the figure, Radio Frequency (**RF**) communications is assumed as it is most widely used and does not have inherent limitations such as line-of-sight requirement in infrared. Wireless Wide Area Network (**WWAN**) covers a large geographical area and consists of telecommunications networks such as Global System for Mobile Communications (**GSM**) and satellite communications. In telephone networks, broadband data is supported with packet-switched data services such as General Packet Radio Service (**GPRS**), **3G**, or Universal Mobile Telecommunications System (**UMTS**). Mobility requirements are critical, as uninterrupted service is expected even when a user is traveling on high-speed rail (**200+ km/h**). Wireless Metropolitan Area Network (**WMAN**) covers geographic area or region that is smaller than **WWAN** but larger than Wireless Local Area Network (**WLAN**). An example of WMANs is **IEEE 802.16** (**WiMAX**). Both **WWAN** and **WMAN** use highly asymmetric devices, as simpler end devices connect to base stations. As such, these networks are intended for single hop uses where the wireless access is used to connect to the Internet or global telephone network. Wireless multihop support is rare and typically limited to base stations.[3. 4].

WLAN spans a relatively small area, such as building or a group of buildings. **IEEE 802.11** is the dominant **WLAN** technology. It was originally targeted to access a wired Local Area Network (**LAN**) with wireless interface but has been since extended to support mesh networking. **IEEE 802.11** is widely utilized for network access in public buildings and enterprises, and sharing Internet in homes. Wireless Personal Area Network (**WPAN**) is a short distance network for interconnecting devices centered around an individual person including watches, headsets, mobile phones, audio/video equipment, and laptops. Bluetooth and **IEEE 802.15** standard family are the most widely used **WPAN** technologies. **WPANs** have varying energy and throughput requirements as the use cases range from low power data exchange with portable devices to high data rate home entertainment and multimedia transfers. **WSN** shares most properties with **WPANs** and may utilize similar technologies. For example, **IEEE 802.15.4** low-rate **WPAN** standard [4] is used as a basis for many **WSN** communication standards. However, a **WSN** is designed for multiple users, has usually more devices, and often emphasizes lifetime.

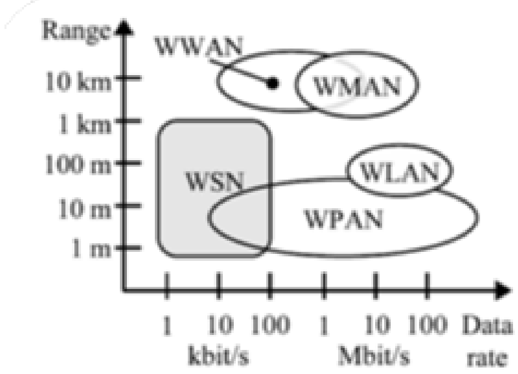

Figure (3): power requirements of the technologies

4. Comparison with Ad Hoc Wireless Networks

- ■ Both consist of wireless nodes but they are different.

☐ The number of nodes is very large
☐ Being more prone to failure, energy drain
☐ Not having unique global IDs
☐ Data-centric, query-based addressing vs. address centric
☐ Resource limitations: memory, power, processing[3]

5. Applications of WSN

Sensor networks are applied in a wide range of areas, such as military applications, public safety, medical, surveillances, environmental monitoring, commercial applications, habitat and tracking. In general, sensor networks will be ubiquitous in the near future, since they support new opportunities for the interaction between humans and their physical world. In addition, sensor networks are expected to contribute significantly to pervasive computing and space exploration in the next decade. Deploying sensor nodes in an unattended environment will give much more possibilities for the exploration of new applications in the real world. In this context, we will look briefly at some of these applications. The idea behind these applications is that; densely deploying sensor nodes with capabilities of sensing, wireless communications, and computation in an unattended environment, will assist in measuring its ambient conditions, and obtaining the characteristics about phenomenon of interest surrounding these sensors; by transforming these sensed/gathered data into electrical signals that can be processed. Moreover, other applications for wireless sensor networks can be seen in environmental monitoring and control field (e.g., robot control), high-security smart homes, tracking, and identifications and personalization [2]. Among these applications are Military applications, Environmental monitoring, Health applications, Automation and control. [5].

Figure (4): Sensor Network Applications Development

6. Model Description

6.1 Typical Wireless Sensor Network

A typical wireless sensor network consists of a number of sensor nodes and a control center. To perform a detection function, each sensor node collects observation data from the surrounding environment, does some processing locally if needed, and then routes the processed data to the control center. The control center is responsible for making a final decision based on all the data it receives from the sensor nodes. Figure **5** shows the structure of a typical wireless sensor network for detection.

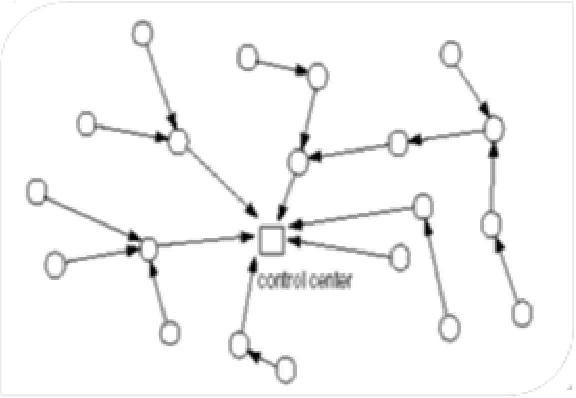

Figure (5): A Typical wireless sensor network.

- **Simplified Wireless Sensor Network Model**

For a wireless sensor network to perform a detection function routing usually is needed to transmit data from faraway nodes to the control center; spatial and temporal correlations exist among measurements across or at sensor nodes; and noise interference must be considered as well. However, to focus our attention on the key issues of detection and energy, we start with a simple model where such considerations are disregarded. Our assumptions for the simplified wireless sensor network model include:[2, 5].

- No cooperation's among sensor nodes**:** each sensor node independently observes, processes, and transmits data.
- No spatial or temporal correlation among measurements**:** An observation is independent across sensor nodes, and at each single node.
- No routing**:** each sensor node sends data directly to the control center.
- No noise or any other interference**:** data are transmitted over an error-free communication channel.

The simplified wireless sensor network model is shown on Figure **6.**

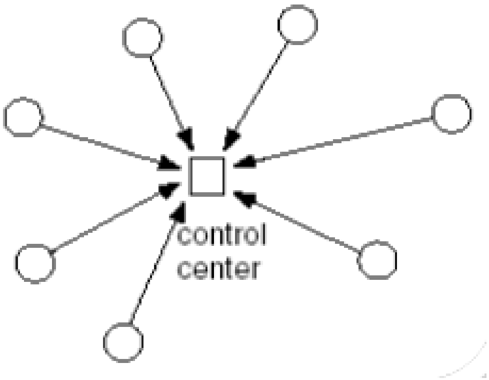

Figure (6): Simplified model.

- **Three Operating Options**

For the simplified wireless sensor network model we propose three operating options with different schemes for local processing and data transmission:

1. Centralized Option. At each sensor node, the observation data are transmitted to the control center without any loss of information. The control center bases its final decision on the comprehensive collection of information.

2. Distributed Option. Each sensor node makes a local decision ($\hat{H}_i$ for S_i**)** and transmits a binary quantity b_i to the control center indicating its decision**:**

$$b_i = \begin{cases} 1 & \text{if } \hat{H}_i = \hat{H}_1 \\ 0 & \text{if } \hat{H}_i = \hat{H}_0 \end{cases}$$

The final decision at the control center is based on the **K** binary quantities

$\{b_1; b_2; \ldots; b_k\}$.

3. Quantized Option. Instead of sending all the information or sending a one-bit decision, each sensor node processes the observation data locally and sends a quantized **M**-bit quantity ($q_i$for S_1, $q_i \in \{0; 1; \ldots; 2^M - 1\}$, $(1 \le M \le T)$ to the control center, and the control center makes the final decision based on the basis of the **K** quantized quantities $\{q_1; q_2; \ldots; q_k\}$. With the operating options well defined, we are ready to analyze and develop the optimal decision rules for them.

6.2 Energy-Efficiency Analysis

- **Energy Consumption Model**

In our analysis we consider only the energy consumed at sensor nodes, and we do not take into account the energy consumption for the control center, which is assumed to have fewer stringent energy constraints. At each sensor node energy is consumed for data processing and data transmission. [1, 4].

Energy for Data Processing Energy consumed for data processing depends on the quantity of processed data and the complexity of the processing operations. Here, by assuming that T; p; p_0, and $p_1$are known prior to the availability of observation data, all the thresholds needed can be computed in advance. Therefore we simply adopt ‘‘comparison’’ and ‘‘counting’’ as the basic operations for data processing, and we assume that the energy consumption for one ‘‘comparison’’ is the same as that for one ‘‘counting.’’ Also we adopt the suboptimal quantization algorithm for the quantized option, so that the thresholds at sensor nodes are determined before the detection. Hence we have a simple model to represent the energy consumed for data processing at sensor nodes as

$$E_p = E_c \times c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where E_c represents the energy consumed for one comparison or one counting, and c is the total number of comparisons and counts involved.

Energy for Data Transmission For the transmission of data from the sensor nodes to the control center, we assume that all the sensor nodes adopt the same communication system and there exists an error-free communication channel over which sensor nodes send data to the control center. Therefore the energy consumed for successfully transmitting one bit of data over a fixed distance is a fixed value for each sensor node. Thus, for our simplified wireless sensor network model, the energy consumption for data transmission is determined by the distances from sensor nodes to the control center and the number of bits transmitted, given other parameters as fixed:

$$E_T = E_t \times d^{\alpha} \times t \quad \ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Here E_t represents the energy consumed for transmitting one bit of data over a unit distance for some fixed communication system, d represents the distance from the sensor nodes to the control center (here we assume that all the sensor nodes have the same distance to the control center), t is the total number of bits transmitted, and α is the path loss exponent. We also assume $\alpha = 2$.

From Equations **(5.1)** and **(5.2)**, the total energy consumption is given by:

$$\mathbf{E = E_p + E_t == E_c \times c + E_t \times d^{\alpha} \times t} \quad \text{............} \mathbf{(3)}$$

For each option, we calculate the energy consumption as follows:

Centralized Option Since the number of **1s** out of the **T** observations

$\{\mathbf{n_1; n_2; ... ; n_k}\}$ are a sufficient statistic, we have two sub options that have the same detection performances.

Suboption 1 — sensor nodes transmit all observations to the control center, which means that there is no local data processing and **T** bits of data is transmitted from each sensor node to the control center. The energy consumed per node therefore is

$$\mathbf{E = E_t \times d^2 \times T} \quad \text{......................} \mathbf{(4)}$$

Suboption 2 — sensor nodes transmit the numbers of 1s **(i.e.,** $\{\mathbf{n_1; n_2; ... ; n_k}\}$) to the control center, which means that each node performs counting **T** times to obtain the number of **1**s, then transmits this $\mathbf{\log_2(T+1)}$ bits quantity to the control center, since $\mathbf{0 \le n_i \le T}$. The energy consumed per node therefore is:

$$\mathbf{E = E_c \times T + E_t \times d^2 \times \log_2(T+1)} \quad \text{.......} \mathbf{(5)}$$

Distributed Option each sensor node counts all the observations to obtain the number of **1s**; then a single comparison with the threshold **γd** is performed to make a local decision, and exactly one bit of data is sent to the control center. The energy consumed per node therefore is:

$$\mathbf{E = E_c \times (T+1) + Et * d^2} \quad \text{.............} \mathbf{(6)}$$

Quantized Option Each sensor node first counts **T** times to obtain the number of **1s**; then the mapping is performed for the suboptimal quantization algorithm. Let **x** represent the expected number of comparisons needed for the mapping. Obviously **x** is a function of **T; M; p ;** $\mathbf{p_0}$, $\mathbf{p_1}$, given by:

$$\mathbf{x} = \sum_{j=0}^{T} x(j) P[ni = j] =$$

$$\sum_{j=0}^{T} x(j)[p_0^j(1-p_0)^{T-j}(1-p) + p_1^j(1-p_1)^{T-j}p] \quad \text{...} \mathbf{(7)}$$

Where $\mathbf{n_i}$ is the number of **1**s at **Si** and **x(j)** is the number of comparisons needed for the mapping when $\mathbf{n_i = j}$. Here we suppose that the comparisons start from $\mathbf{I\,(2^{M-1}+1)}$ and continue to the adjacent threshold one by one.

Specifically, **j** is first compared with $\mathbf{I\,(2^{M-1}+1)}$; **if** $\mathbf{j \ge I\,(2^{M-1}+1)}$, **j** is next compared with $\mathbf{I\,(2^{M-1}+2)}$, otherwise **j** is compared with $\mathbf{I\,(2^{M-1})}$, and so on until $\mathbf{I(k) \le j \le I(k+1)}$ is found, then $\mathbf{q_i = k - 1}$ is determined. For example, when **T = 20**; **M = 3; p = 0.5;** $\mathbf{p_0 = 0.2}$**,** and $\mathbf{p_1 = 0.7}$, the set of thresholds for the suboptimal quantization algorithm is calculated to be **{0; 6; 7; 8; 9; 10; 11; 12; 21}**; then **x** can be computed as:

$$x(j) = \begin{cases} 4 & \text{if} \quad 0 \le j \le 6 \text{ or } 11 \le j \le 20 \\ 3 & \text{if} \quad j = 7, 10 \\ 2 & \text{if} \quad j = 8, 9 \end{cases}$$

The total energy consumed per node is given by$\mathbf{E = E_c \times [T + x(T, M, p, p_0, p_1)] + E_t \times d^2 \times M}$ **...... (8)**

7. Numerical Results

In the following numerical examples, we adopt the suboptimal quantization algorithm for the quantized option to evaluate the energy consumption performance.

- Energy Consumption Comparison for Fixed **E_c; E_t; d** as a Function of **T**. We fix **E_c= 5 nJ/bit**, **E_t= 0.2 nJ/ (bit *m_2)**, **d = 10 m**, and **p = 0.5; p_0= 0.2; p_1= 0.7**; we vary **T** from **5** to **100** and **M** from **2** to **5**. Figure **(7)** shows the energy consumption per node versus **T** for all schemes of three options.

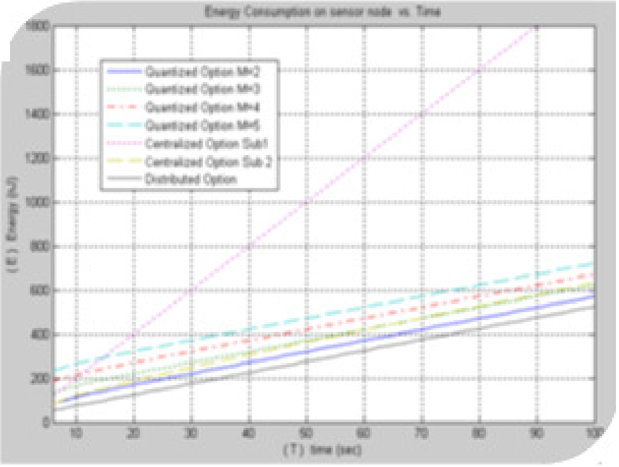

Figure (7) E versus T for all schemes

- Energy Consumption Comparison for Fixed **T** as a Function of **E_c; E_t; d**. First we fix **T = 10; M = 2; p = 0.5; p0 = 0.2, and p1 = 0.7**; then we vary **d** from **5** to **50 m**. Figure **(8)** shows the energy consumption per node versus d for the three options with different values of **E_c**and **E_t**.

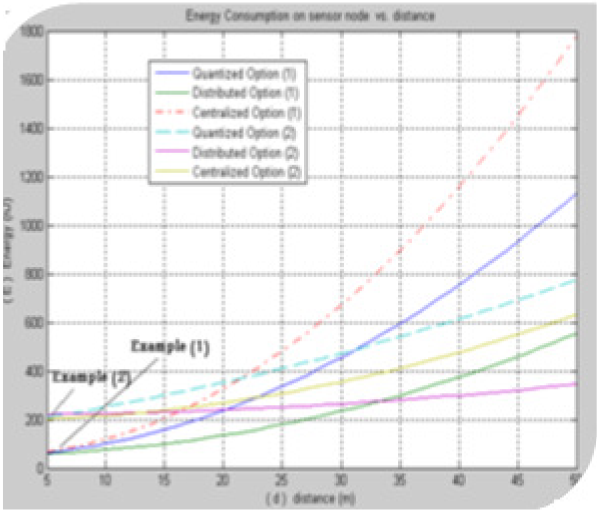

Figure (8) E versus d(T = 10;M = 2)

- Then we change **T** to **50** and **M** to **4,** and all the other parameters remain unchanged. Figure **(9)** shows the new curves. Here we examine the following two examples for different values of **E_c**and **E_t**and adopt suboption **2** for the centralized option:

Exemple 1: **E_c= 5 nJ/bit, E_t= 0.2 nJ/(bit *m2)**

Exemple 2: **E_c= 20 nJ/bit, E_t= 0.05 nJ/(bit *m2)**

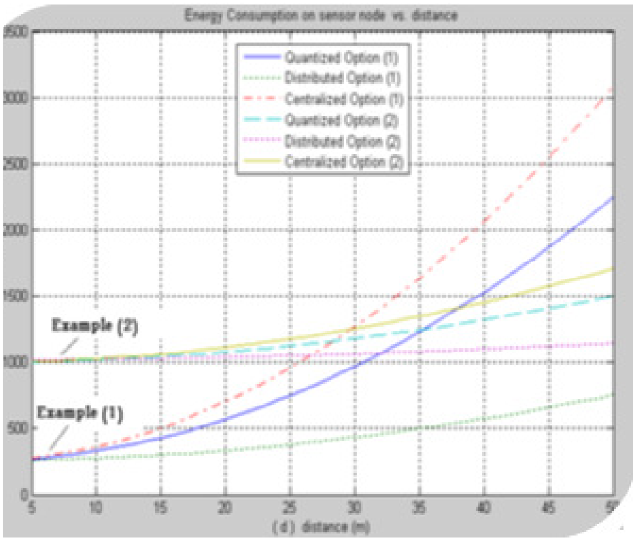

Figure (9) E versus d(T = 50;M = 4)

As we expected, for the low $\mathbf{E_c}$–high $\mathbf{E_t}$ case (e.g., **example 1**), the distributed option performs best in the sense that it has the least energy consumption, while the centralized option has the worst performance. On the other hand, for the high $\mathbf{E_c}$–low $\mathbf{E_t}$ case (e.g., **example 2**), the centralized option performs best for small **d**; however, its energy consumption rises rapidly with the increase in d and eventually exceeds of the other two options. The distributed option has the best performance for large **d** in this case.

- By using **MATLAB** we simulate the Energy Consumption in sensor node for data processing, data transmitting and total energy (i.e. both processing with transmitting) at $\mathbf{E_c}$**= 50 nJ/bit** and **c** or **t** it the input (ramp function) and initial value start from **0** for three cases, also **c** & **t** are represented the bit data packet from node to other node where $\mathbf{E_t}$**= 100 pJ/bit** and assume that **d = 5m**. When we simulate the total energy supposes **c** and **t** is equal. From the figures below **(5.5), (5.6)** and **(5.7)** relationship between energy and bit data packet from node to other node.

8. .Conclusion and recommendation

A wireless sensor network is a collocation of nodes organized into a cooperative network each node consists of processing capability (one or more microcontrollers) may contain multiple types of memory also each of them has **RF** transceiver have a power source, this new technology is exciting with unlimited potential for numerous application areas including environmental, medical, military, transportation entertainment, crisis management, homeland defense, and smart spaces.

In this paper we have been modeled the energy consumption at the sensor nodes, so the energy efficiency as a function of system parameters, also it has been compared for a three options, according to the result that . we obtained, the distributed option has the best performance for low values of $\mathbf{E_c}$ and high values of $\mathbf{E_t}$ for high $\mathbf{E_c}$ and low $\mathbf{E_t}$, the centralized option is the best for relatively short distances from sensor nodes to the control center, while the distributed option is the best for long distances.

We have been use the **MATLAB** simulator to simulate the energy performance, so we recommended to use another simulator which is used for wireless sensor network like **NS2**, **J-sim**, **GlomoSim**, and **JavaSim.** Also it's up to anyone to simulate the detection performance or robustness performance or delay by using Matlab. 2012a.

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