Efficient Multimedia Services Provision over Cognitive Radio Networks using a Traffic-oriented Routing Scheme

Constandinos X. Mavromoustakis\textsuperscript{1}, George Mastorakis\textsuperscript{2}, Athina Bourdena\textsuperscript{2}, Evangelos Pallis\textsuperscript{2}

\textsuperscript{1}University of Nicosia, Department of Computer Science, Nicosia, Cyprus
Tel: +35722841730, Fax: +357-22357530, Email: mavromoustakis.c@unic.ac.cy

\textsuperscript{2}Technological Educational Institute of Crete, Department of Informatics Engineering, Estavromenos, Heraklion, Crete, Greece
Tel: +302810379828, Fax: + 0302810379717, Email: gmastorakis@staff.teicrete.gr, bourdena@pasiphae.eu, pallis@pasiphae.eu

Abstract

Mobile networks community is witnessing an unprecedented demand for multimedia services with the immense popularity of Internet. Wireless connections are increasing day by day with the growing ability to interconnect computers through broadband connections and proportionately a new class of services based on multimedia data dissemination is also increasing. One of the major concerns of these applications is to deliver multimedia data within a time limitation and guarantee a bounded or minimum delay, whereas at the same time, the energy consumption of the wireless devices has to be minimized. This chapter takes into consideration the activity of the traffic, in order to impact the nodal scheduling policy and the associated activity slot durations of each node to conserve energy. More specifically, the chapter presents a resource intensive traffic-aware scheme, incorporated into an energy-efficient routing protocol that enables maximum energy conservation and efficient multimedia based data flow coordination, among
secondary communication nodes with heterogeneous radio spectrum availability in cognitive radio networks. Guaranteeing a predetermined or precise Quality of Service (QoS) level, through the expected access time or delay, bandwidth and the traffic pattern of the stream are perhaps the most salient features of such multimedia services provision. To this end, and in order to extract the best performance and energy efficiency for wireless devices, a scalable and efficient multimedia transmission scheme, which encompasses the traffic manipulation is needed. The proposed scheme associates the backward difference of the traffic moments of each node, according to a Fibonacci model, with the sleep-time duration, in order to tune the activity durations of a node for achieving optimal energy conservation and efficient multimedia streams provision over cognitive radio networks. Efficient routing protocol operation, as a matter of maximum energy conservation, maximum-possible routing paths establishments and minimum delays is obtained, by utilizing a signaling mechanism, developed based on a simulation scenario that includes secondary cognitive radio nodes, operating over television white spaces (TVWS). The validity of the proposed Fibonacci-based Backward Traffic Difference (F-BTD) is thoroughly evaluated and the energy-efficient routing protocol is verified, by conducting experimental simulation tests and obtaining performance evaluation results. Simulation results validate the efficiency of the proposed traffic-aware scheme and the effectiveness of the proposed routing protocol, for minimizing energy consumption, maximizing multimedia resource exchanges between secondary cognitive radio networking nodes and minimizing routing delays during multimedia streams provision.

1. Introduction

Emerging types of wireless applications and mobile services, rich in multimedia content with high demands for network resources and strict Quality of Experience (QoE) requirements, put more and more pressure for further research on efficient multimedia services provision over future generation communication systems. Such communication systems will enable the provision of customized user-centric services, ranging from entertainment and lifestyle applications (e.g. mobile TV) to professional services such as video conferencing and real-time data exchange. Suitable platforms and gateways are under development to enable the provision of a wide array of new services to meet users’ demands. The major challenge of such new services arises as a matter of the required demands of wireless users’ devices for energy consumption. Another vital issue is the guaranteed QoS of different multimedia services, in cases of unexpected delays or network failures. For instance, failures or delays are very common in future networking environments, exploiting “televison white spaces” (TVWS) [1], where the radio spectrum is available at local level and thus the communication among nodes is difficult to be obtained. The opportunistic exploitation of TVWS can be performed by Cognitive Radio (CR) technology [2], which constitutes an emerging communication paradigm. CR networks are capable to interact with the surrounding spectral environment, by sensing the wide radio spectrum, dynamically identifying the local available frequencies and efficiently exploiting them. However, the introduction of CR networks in TVWS hampers the current “command-and-control” paradigm of TV/UHF spectrum management, thus the operation of CR technology in TVWS is highly associated with the regulation models that would be adopted [3], [4], [5]. For instance, “Spectrum of Commons” is a recent spectrum regulation model that permits the coexistence of primary and secondary users in the same spectrum band (i.e. UHF), on condition
that the latter do not cause interference to the former. It is especially applicable in distributed/ad-
hoc CR networks, where resource allocation is locally administrated/handled by communication
nodes, in contrast to adopt a centralized network approach that exploits a spectrum manager [6].
In addition, the opportunistic radio exploitation, by ad-hoc CR networks, provokes new issues in
the design of communication protocols, in several network layers. For instance, the design and
adoption of novel routing schemes in the network layer, are required for the efficient provision of
emerging multimedia services, in order to avoid route failures and to establish and maintain fixed
routing paths between secondary communication nodes. Beyond the route establishment, another
challenge is to provide and guarantee the desired QoS level to mobile wireless end users that are
also energy harvest.
Energy saving presents a significant element/aspect in cases of the high performance deployment
in ad-hoc CR networks. More specifically, the energy harvest wireless nodes have to be tuned to
the calculated values (i.e. capacity, traffic [7] of the nodes) of the energy saving/conservation
scheme, while the latter (i.e. scheme) has to take into account the bounded end-to-end delays of
the nodes’ transmissions. Considering the above mentioned issues, it is resulted that the network
lifetime is firmly correlated/associated to the transmission characteristics [8] of a source node to
a destination node, while the selected routing protocol [9], combines both the temporal traffic-
aware behaviour of the node [10] and the efficient routing scheme in an end-to-end path. This
vital issue has already been studied in the research work proposed in [8], where the authors
designed a resource intensive traffic-aware scheme for energy saving in wireless devices. More
specifically, in the proposed scheme a number of sleep-proxy nodes are exploited, in order to
evaluate the duration of the activity periods of each node. This evaluation is performed according
to the capacity, as well as according to the estimated inter-cluster overall energy consumed
within a time frame. Towards further investigating the scheme proposed in [8], the current work is an enhanced scheme that exploits the Fibonacci-based Backward Traffic Difference (F-BTD), which aims to extend the lifetime of the secondary nodes of the CR network. The proposed F-BTD scheme recognizes the activity of incoming traffic and accordingly permits the nodes to adaptively sleep. The proposed traffic-aware scheme examines the traffic active moments of the nodes, as well as the volume of the traffic for a specified time window frame, in order to adjust the activity of each node based on the energy efficient metrics of the CR secondary nodes. In order to minimize the energy consumption of each node, the Backward Traffic Difference measures the volume of the incoming Traffic that is intended for each node within a time window frame. The Backward Traffic Difference [10], [11] considers the repetition of the Traffic and estimates the Backward Difference of different moments, in accordance to the Fibonacci sequence for extracting the time duration for which the node is allowed to Sleep.

In this context, this chapter elaborates on the design, development and experimental evaluation of a resource intensive traffic-aware scheme and an energy-efficient routing protocol for ad-hoc CR network architectures, enabled for the efficient communication of secondary communication nodes that operate under the “Spectrum of Commons” regime, offering effective multimedia services provision. More specifically, a signaling mechanism combined with an energy efficient scheme is proposed, in order to support multimedia services in an end-to-end manner. The mechanism is based on the Backward Traffic Difference estimation [7], [8], [10] in contrast to the end-to-end bounded delay of the transmission. The wireless ad hoc networks need to be supported by improved system reliability and availability through the automatic traffic measurements and configuration of traffic-aware network parameters. Based on the underlying routing scheme and the volume of traffic that each node receives/transmits, the proposed scheme
aims at minimizing the energy consumption by applying asynchronous, non-periodic sleep-time assignment slot to the secondary wireless nodes according to the F-BTD scheme. The F-BTD scheme is applied in order to enable delay-sensitive multimedia contents in an end-to-end reliable manner. Following this introductory section, section 2 elaborates on related work and research motivation, while section 3 presents the design and development of a novel green-aware routing protocol, offering energy efficient data transition, across secondary communication nodes with different TVWS availability. In order to achieve an energy-efficient methodology, the proposed framework uses a traffic-aware Backward Traffic Difference scheme based on Fibonacci sequence model for estimating the duration of the sleep time according to the nodal traversed traffic. With the Backward Traffic Difference applied scheme, multimedia resources are treated in a prioritized manner so that requested traffic is forwarded to the destination node within a specified amount of time. The proposed scheme allows persistence to be ensured through the promiscuous caching mechanism. The persistence is enabled through the ability of data multimedia objects to survive through different resource sharing environments and invocations. The proposed scheme guarantees the end-to-end availability of requested multimedia resources, while it significantly reduces the energy consumption and maintains the requested scheduled transfers, during the resource sharing process. For achieving energy conservation the proposed traffic-aware policy can efficiently determine the ON and OFF duration/period of each node, which then effectively provides the reflective effects to the overall energy consumed by nodes. Section 4 elaborates on performance evaluation analysis of the proposed research approach, discussing experimental results and Section 5 concludes this chapter, by highlighting directions for future research.
2. Related work and research motivation

Several research approaches have been proposed for the efficient multimedia services provision over cognitive radio networks towards increasing radio spectrum availability, as well as avoiding delays and interference that is usually caused among secondary and primary nodes. CR technology aims to enhance the spectrum utilization in the licensed frequencies and provide high-throughput communication by optimally selecting communication paths and channel assignments. There are many approaches proposed to optimally share the radio spectrum, by exploiting cognitive radio technologies in different use-case scenarios. Research work in [12] analyzes multimedia transmissions over CR networks with the proper admission control and the appropriate channel selection. In [13], the authors investigate the impacts of the dynamic resources on the smooth video streaming in CR networks and propose a centralized channel allocation algorithm to achieve superior video delivery, by reducing the playback frozen probability. Authors in [14], manage the problem of multimedia service provisioning in the context of a multi-channel CR network. For this scope, the proposed framework for multimedia services, considers the channel heterogeneity among different secondary users, as well as the feature of multicast transmission. This effective framework is capable to incorporate cooperative transmission between users into direct transmission from the secondary base station. In addition, authors in [15] study the multi-hop communication by proposing an efficient routing scheme, in order to improve the connectivity and the spectrum efficiency of the cognitive radio users. The correlation of multi-hop transmission with routing in CR networks is capable to reduce the transmission power, as well as to improve the network connectivity and the spectrum efficiency. Research work in [16] proposes a solution for the multimedia transmission problem over CR networks in lossy environments. Consequently the primary traffic interruptions are not the only
reason leading to packets losses that are also caused by collisions between secondary users due to concurrent access in spectral resources. The transmission performance of a multimedia stream over CR networks is affected by two critical factors; on one hand interferences caused by the primary user reclaims for resources, leading to more corrupted secondary packets, and on the other hand collisions caused by the opportunistic transmissions of the secondary users. Authors in [17] elaborate on spectrum opportunities that are varying over time and locations in CR networks. The exploitation of multichannel routing schemes is capable to significantly improve the throughput of multi-hop wireless networks, since the interference can be avoided or reduced and the network load can be balanced on different channels [18]. Nevertheless, the routing mechanism has to be strictly associated with the Energy-efficiency when the CR networking architecture hosts wireless nodes requesting spectrum, via which the traffic will be transferred. Therefore the routing mechanism in collaboration with an energy-efficient scheme should guarantee the end-to-end availability of requested resources, whereas it should be able to significantly reduce the Energy consumption. In addition, the mechanism should be able to maintain the requested scheduled transfers and the entire end-to-end connectivity. In such networks, energy efficient routing schemes achieve higher performance than the shortest routing-path schemes, while at the same time, reduce the power consumption of the relay users [19]. In addition, the energy efficient routing schemes disburden the network-partitioning problem that is caused by the energy exhaustion of the relay nodes. For this scope the researchers of the work in [19] try to provide a high throughput routing approach, which involves not only in route selection but also in channel-timeslot allocation. Thus the traffic is decomposing over different channels and timeslots. Also, the work in [20] presents promising CR networks with advanced functionalities that require sophisticated information processing capabilities. The CR networks
need powerful energy sources to afford all these functionalities. Consequently, the current battery technologies cannot meet the enormous increase in power consumption related to the increasing traffic flow resulting from the improvement in fast semiconductor technologies [21]. In this way, energy efficiency may become a limiting factor in the development of advanced wireless communications technologies. Research for higher energy efficiency is primarily due to three reasons, the cost-effectiveness, the longer battery lifetime and the environmental concerns. Energy costs are constantly increasing and energy expenditure of a wireless network is a significant fraction (20 to 30 per cent [22]) of total operator expenditures (site rental, licensing etc.). Hence, energy should be effectively consumed for cost-effective systems. Reducing energy consumption and energy-efficiency operation is thereby at the interest of the operators. From the user viewpoint, energy efficiency means longer battery lifetime. It is a fact that short durations between two battery charging annoy the users and reduce the practicality of wireless communications. Thus, energy efficiency is vital for both actors of wireless communications.

In addition, many recent measurement studies [11] have convincingly demonstrated the impact of Traffic on the end-to-end connectivity [23], and thus showed the impact on the Sleep-time duration and the Energy Consumption. Measures extracted in real-time using realistic traffic [11], [23] have shown that the impact of the responsiveness of the routing scheme in regards to the end-to-end transmission reliability is significant. Real-Time communication networks and multimedia systems, exhibit noticeable burstiness over a number of time scales as explored in [24], [25]. Based on the stochastic traffic modelling, the traffic in most of the cases can be expressed in time exhibiting fractal-like characteristics [26]. The exploration of a scheme where, in collaboration with the routing mechanism used, takes into account the traffic pattern in order to reflect this pattern on the activity durations of the nodes for conserving energy, has not yet
investigated. The scheme will be able to tune the wireless interfaces of the nodes into the Sleep or Active state according to the pattern of the incoming Traffic and will be capable to reflect this pattern –through a model- onto the next Sleep-time duration of each secondary node. Existing scheduling strategies for wireless nodes could be classified into three categories: the coordinated sleeping [27], where nodes adjust their sleeping schedules, the random sleeping [26], where there is no certain adjustment mechanism between the nodes in the sleeping schedule with all the pros and cons [10], and on-demand adaptive mechanisms [28], where nodes enter into Sleep-state depending on the environment requirements whereas an out-band signaling is used to notify a specific node to go to sleep in an on-demand manner.

Although there are many schemes proposed in order to deal with the Energy conservation issues, the correlation of a traffic-aware scheduling scheme with the underlying routing protocol supported by the CR networking architecture has not yet been explored. This correlation scheme poses a fruitful ground for the deployment of new approaches with the association of different parameters of the communication mechanisms, in order to maximize the Energy saving. Such schemes are classified into active or passive mechanisms. Active techniques sustain energy by executing energy conscious operations, such as transmission scheduling and energy-aware routing. Mavromoustakis et al. in [11] considers the correlation of Energy conservation issue with a number of parameterized characteristics of the traffic (like traffic prioritization) and enables a mechanism that tunes the interfaces’ scheduler to expand in the sleep state based on the activity of the traffic of a certain node in the end to-end path in real-time. When nodes request multimedia resources, the underlying mechanisms should enable in a prioritized manner the guarantee of the end-to-end delay that will be fulfilled by the requested transfer. To this end, the mechanism should enable an adaptive forwarding capability in order to provide the destination
and end-nodes with the data requested, within a specified amount of time. The proposed scheme guarantees the end-to-end availability of requested multimedia resources, while it significantly reduces the energy consumption and maintains the requested scheduled transfers while it fulfills the delay constraints and requirements by multimedia resources. The presented research work deals with the minimization of the secondary nodes’ energy consumption by deploying a temporal pattern of the incoming Traffic. The proposed scheme tries to maximize the energy saving of each secondary node, by exploiting the Fibonacci-based pattern of the Traffic, as well as the delay limitation (bounded delay) of each transmission. The time-oriented sequence of the incoming traffic, as well as the communication traffic volume (data and control packets) among peers are consult by the proposed scheme as a solution for the provision of energy conservation schedules of the communicating secondary nodes. To this end, a prototype traffic-aware methodology is exploited throughout the resource exchange process between nodes, by applying to the Backward Traffic Difference (BTD) scheme [29] a discrete Fibonacci backward estimation for deriving the time-oriented differential traffic. Through the proposed approach, each node evaluating at the same way, the differential dissimilar assignment(s) of sleep-wake schedules for each of its traffic moments. Moreover, the sleep-wake schedules operate according to the traffic difference over time, the relative nodal capacity and the associated traffic characteristics. The main challenges that achieve the proposed scheme deals with the guaranteed end-to-end availability of the resources, the decrement at a notable level of the energy consumption, while it also maintains the requested scheduled transfers, during the resource distribution process. For further availability of the spectrum opportunities, the scheme exploits opportunistically the methodology of the promiscuous caching [10], aiming to cache the packets destined for the node with turned-off interfaces (sleep state) onto intermediate nodes. The proposed energy-saving
framework, based on the Backward Traffic Difference estimation, with the proposed routing methodology enable, the next Sleep-time duration of the recipient node to be adjusted according to the activity duration and the volume of the traffic in collaboration with the consolidated routing mechanism.

3. Energy efficient routing scheme for multimedia services provision over cognitive radio networks

The main challenge in an ad-hoc CR network environment is the proper communication among secondary nodes exploiting the available TVWS for the efficient provision of multimedia services. A routing protocol in this case has to consider the available spectrum opportunities, in different geographical regions at local level. Issues such as the spectrum awareness, the route quality and the route maintenance are crucial for the design and implementation of an efficient routing scheme. These attributes may enable for optimum data delivery across locations/areas with dispersed radio spectrum opportunities, even if network failures in the path exist due to primary nodes’ transmissions.
Figure 1 illustrates a simulation scenario in a heterogeneous spectrum environment. In this scenario, the incumbent systems (Primary Systems in Figure 1) operate over specific channels in three geographical regions (i.e. Area A, B and C in Figure 1). On the other hand, secondary nodes are able to operate in an opportunistic manner, by exploiting the remaining vacant channels (i.e. TVWS) in each geographical region. The main challenge for the proper communication of the secondary nodes is the lack/absence of a Common Control Channel (CCC). Secondary nodes of Area A cannot operate over a common channel with secondary nodes of Area B and C, thus an inconsistency exists for the creation and maintenance of a routing path delivering multimedia streams. For this purpose, secondary nodes that are located in regions with higher TVWS availability (e.g. locations outside areas A, B and C) act as intermediate relay nodes.
nodes, switching to alternative channels in order to enable for the establishment of a routing path between secondary nodes of regions A, B and C.

Considering the above-mentioned scenario in an ad-hoc CR networking environment, spectrum awareness has to be examined, in order to provide high throughput data delivery and effective multimedia services provision by optimally choosing the most efficient routing paths between secondary nodes. In this framework, a prototype routing protocol has to be adopted, in order to enable the discovery of routing paths taking into account the protection of incumbent systems, as well as the TVWS heterogeneity in different regions. In addition, route quality issues are crucial in the design of a routing mechanism, since the actual topology of such multi-hop CR networks is highly affected by primary nodes behavior, while the classical ways of evaluating the quality of end-to-end routes, such as bandwidth and throughput are no longer enough. In a general context, communication issues for efficient multimedia services provision in an ad-hoc CR network over TVWS comprise an important and yet unexplored problem, especially when a multi-hop network architecture is examined. Hence, a novel routing protocol is crucial to be designed and implemented, in order to solve the problems described, concerning the establishment and maintenance of efficient routing paths, among communication nodes with different radio spectrum availability.

3.1 Proposed underlying routing mechanism

The relay/intermediate secondary nodes of the proposed scenario are permitted to operate over all the available TVWS (i.e. c.40-c.60) and act as bridge nodes, while they can grand information by the Geo-location database regarding the TVWS availability. These relay nodes are also enhanced with routing capabilities, enabling to determine optimum routing paths among the secondary nodes for efficient multimedia services provision. Towards enabling for the delivery
of delay sensitive multimedia services between secondary communication nodes, a novel routing protocol was designed, implemented and evaluated, by conducting experimental simulations. The proposed routing protocol exploits the exchange of ad-hoc on demand distance vector (AODV) messages [30] between secondary nodes, considering both the route discovery and the route reply processes. The exploitation of these hop-by-hop messages enables for the prediction of the vacant TVWS, thus these messages are broadcasted only in cases that are necessary. Throughout the route discovery process, a RREQ (route request) message that encompasses the available TVWS of the neighbor nodes, is broadcasted by the source node in order to obtain a route path up to the destination node. Once the destination node receives the RREQ message, it has a full knowledge regarding the available TVWS along the route path. Finally, the destination node selects the optimum routing path, as a matter of minimum number of hops and delay (e.g. backoff delay, switching delay, queuing delay) and assigns a channel to each secondary node along the route. More specifically, each intermediate node conducts the evaluation of the delay metrics though the RREQ message that forwards to the next node, while the metric evaluation is defined as $E_{ni}$ (see Table 1), where $E$ is the end-to-end delay in millisecond and $n_i$ represents the $i^{th}$ intermediate node that obtains the path. Also, $E_n$ represents the delay occurred during the RREQ message. In the next step of the proposed process, destination node sends back a RREP (route reply) message to the source node that encompasses information regarding channel assignment.

Figure 2 presents the sequence diagram of the proposed routing mechanism for handling the communication among secondary nodes by swapping route request and route reply messages. More specifically, a secondary source node initializes a new flow by transmitting a RREQ message to the closest neighbor secondary intermediate node that transmits in a common
channel. As soon as each intermediate node receives a RREQ, it evaluates the delay of the flow (i.e. queuing delay), while it is also informed about the status of the neighbor secondary nodes by the Geo-location database. Then each intermediate node decides whether or not it will perform the accommodation of the flow based on the delay evaluation. In case that the delay is decreased (comparing with the previous delay values in the path), the node accommodates the flow and forwards the RREQ message to the next hop (i.e. next intermediate node). As soon as, the destination node receives the RREQ, it has full knowledge for the TVWS availability along the routing path. Following this, the destination node responses to the source by broadcasting a RREP message that includes relevant information, concerning the channel allocation for the path. This process establishes the routing path and the useful data transmission is initiated.

Figure 2. Message exchange process of the proposed routing protocol
Alternatively, if the intermediate node is not capable to serve the incoming flow, a redirection process (redirection in Figure 2) is in charge of informing the source node, about the status of neighbouring nodes, which could possibly act as an alternative intermediate node. The proposed routing protocol obtains a route, in cases that a source node wants to initiate data flows to a destination node. The obtained routes are maintained as long as they are necessary, while the use of sequence numbers in the exchange messages guarantees a loop-free routing process. The proposed routing protocol operates on a demand basis, as it creates and maintains the routes in cases that are necessary, thus it characterized as a “reactive” one. In such a case, routing tables are exploited in order to maintain the routes, where each entry of the table contains information, concerning the destination node, the next hop, the number of hops, the destination sequence number, the active neighbouring nodes for this route and expiration time of the flow. It has to be noted, that the number of RREQ messages sent by a source node per second is limited, while each RREQ message contains a time to live (TTL) value that specifies the number of times this message could be re-broadcasted. This value is set to a predefined value at the first transmission and is increased during retransmissions that may occur in cases that no replies are received.

Towards further optimizing the proposed routing protocol, an assigning mechanism was implemented in order to provide relieve to the intermediate nodes, in cases that the service load is high. The assigning mechanism is incorporated to each intermediate node, which is further able to determine if a neighbor node performs better during the process of routing paths establishment. The process in the sequence diagram of Figure 2 is more or less the same, however the main difference is that when an intermediate node receives the RREQ, it evaluates the obtained path and includes the delay evaluation in the RREQ message in order to forward it to all neighbouring nodes. Once neighbouring nodes receive the RREQ, they evaluate the path
and send back to the intermediate node the measured delay evaluation through a redirecting reply message. Once the intermediate node receives the redirecting reply from several of its neighbouring nodes, it then determines the optimum one, in order to obtain the next hop in the path, considering the mitigation of the traffic in the nodes queues. The pseudocode of the proposed assigning mechanism is summarized in Table 1. For enabling Energy-Efficiency and achieving minimum delays for delay-sensitive multimedia services in the proposed framework, a Backward Traffic Difference (BTD) estimation [11] methodology is used. The main additional contribution is that, in the proposed framework, the BTD estimation is bounded by the delay limitations of the transmission, whereas it takes into consideration the hop-by-hop link delay as well as the total end-to-end delay of the transmission. The bounded delay evaluation scheme has been encompassed in order to enable end-to-end transmission in an efficient manner, whereas it will enable the reliable and correct transmission of multimedia services. In addition, the Fibonacci-based association of the incoming traffic is measured using the BTD in an adaptive way, by measuring the discrete Fibonacci sequence of the incoming traffic of each node. According to the proposed algorithm, each node evaluates in real-time the F-BTD and associates the optimal sleep-time duration to each node’s life-cycle. The later should satisfy the delay requirements of the transmission. Considering the delay limitations in a multimedia service, it is difficult to maintain QoS for certain multimedia applications i.e. voice. The designed model guarantees the end-to-end availability of requested resources while it reduces significantly the Energy Consumption and maintains the requested scheduled transfers, in a mobility-enabled communication. In order to achieve a reasonable transmission guarantee and reliability degree in the service provision by the wireless devices, an adaptive scheme must be hosted in the end-to-end resource exchanging process. The innovation adopted in this scheme is that each secondary
mobile node uses different assignment(s) of sleep-wake schedules based on the incoming traffic
difference that each node receives through time in order to prolong each node’s lifetime and
allow multimedia services to be supported in a reliable manner. The scheme assigns the Sleep-
time duration according to the BTD scheme in a dissimilar manner in order to enhance node’s
lifetime, whereas it avoids mutation, which, will result in network partitioning and resource
sharing losses. This configuration allows the multimedia services to be adequately provided to
the end-recipients.
1: Initiate New Flow “f” by sending a RREQ
2: Update Intermediate Node “I” with neighbour status
   //Calculate the delay of the flow “f” from the source node to the 1st intermediate node “I”
3: $D_n = D_{queuing} + D_{switching} + D_{backoff}$
4: k = number of intermediate nodes
   //Decision of node “I”
5: for (i=1; i++; i=k){
   //Calculate the delay of the flow “f” from the 1st intermediate node “I” to next intermediate node “NI”
6: $D_{ni} = D_{queuing,i} + D_{switching,i} + D_{backoff,i}$
7:   if $D_{ni} < D_n$
8:     then flow accommodation
9:   until (receive route acceptance)
10:  generate and send RREP to source node
11:  start data transmission
   //Flow redirection, the i\textsuperscript{th} intermediate node generates and broadcasts redirection information message
12:  else if $D_{ni} > D_n$
13:    redirection process
14:    go to steps 6-14
Table 1. Pseudocode of the basic steps of the proposed message exchange process

Assuming that a mobile secondary node has already used the depicted routing scheme of the previous section and established an end-to-end connection in order to transmit requested content/packets. Routing occurs on the end-to-end basis and each node separately runs the Traffic-aware mechanism using the BTD as is described in the following section. The mechanism measures the traffic that traverses each one of the nodes where, the F-BTD estimation through the assigned time-window frame will affect the Sleep-time duration and enable Energy conservation onto nodes as conducted simulation experiments show.

3.2 Traffic-aware scheme for energy-efficient transmission

3.2.1 Traffic-driven Middleware and supported mechanisms

As wireless devices have many constraints in terms of processing, battery and achievable data rate, the proposed scheme aims at guaranteeing the reliability of the requested resources within a specified amount of time and within the allowed time frame that the multimedia resources need to be transferred. In essence, efficient mobile exchanging process becomes complex because of the devices’ characteristics and the components change in time, as well as in space in terms of connectivity, portability, accessibility/availability and mobility. Towards reducing the impact of these changes, the resource sharing application must have a context-aware adaptive behavior. Context-aware through traffic-aware adaptation is a fundamental concept for pervasive and ubiquitous environments. In collaboration with the proposed routing methodology used, this chapter elaborates on the traffic volume exploitation and manipulation, and its direct impact on the EC mechanism. Traffic-aware policy requires an active scheme to be applied, through which,
the traffic will reflect a certain impact on the nodes taking into account the EC trade-offs. Wireless devices should consider the incoming traffic, in order to adapt and reflect a certain feedback according to the traffic volume to the energy conservation mechanism. A middleware, which hosts traffic changes and has a direct impact through the estimated scheme presented in the next section using a collaborative traffic-aware scheme, is shown in Figure 3. This figure depicts a cross layer interaction through a mechanism for traffic-awareness in an end-to-end manner. In particular, real-time media traffic, such as voice and video typically have high data rate requirements and stringent delay constraints, whereas wireless nodes generally have limited or momentarily connectivity. The proposed middleware enables data packets to be traversed and manipulated through the utilized Wireless Data Link, Network, and Transport layers, by considering the traffic awareness mechanism and the model for volume estimation to be reflected on these layers. The proposed traffic-aware scheme and the associated mechanisms evaluate (after the bootstrap process of the system) the estimated (quantified as Volume/Capacity) traffic that is destined for each node. In Figure 3, the $V^i_k$ denotes the volume of traffic destined for node $k$ and stored onto node $i$ using the promiscuous caching policy [10]. In this way, it enables – through the proposed mechanism- estimation for the next sleep duration of the node-as presented in the next section. This traffic-aware policy and the sleep duration evaluation are performed in an interactive way through the Backward Traffic Difference (BTD) using a certain window frame-size. These mechanisms are performed, in order to tune the wireless interface of each device to sleep/wake, according to the activity of each individual device in the resource exchanging path.

Packet classification methodology was utilized as in [10], in order to mark the packets that are exchanged whether they are delay sensitive or not. In turn, if packets are considered as delay
sensitive, strict deadlines are applied by the sender, according to the specifications set in the network. In the case where packet deadlines cannot be satisfied, then cached packets of nearby nodes, enable recovery using the promiscuous caching. This buffering mechanism for multimedia resources enables the resources’ replication and increases the resource sharing reliability. The mechanisms shown in Figure 3 are depicted in the following sections with the quantitative analysis.

![Traffic-aware Middleware](image)

**Figure 3.** The traffic-aware interactive middleware mechanism with the associated influenced layers in the communication stack

The proposed scheme introduces high availability capabilities for resource sharing allowing for continuous operation and smoother handling of system outages. The promiscuous caching mechanism estimates the volume of traffic that is cached on an intermediate (active state) node in the path, in order to measure the volume of traffic that is outage. The traffic-aware middleware
that hosts the resource intensive scheme allows a more flexible system infrastructure that can adapt to dynamic changes in resource sharing application requirements and connectivity conditions. As the reflective middleware model is a principled and efficient way of dealing with highly dynamic environments, the proposed scheme yet supports a reflective and flexible adaptation of the traffic volume $V_i^t$. The multimedia traffic is considered in terms of the repetition pattern by estimating the Backward Difference for extracting the time duration for which the node is allowed to reduce the Energy consumption by entering the Sleep state during the next time slot $T$. The middleware in collaboration with the proposed routing scheme enables secondary nodes to exchange efficiently the requested resources by evaluating within a time frame window the incoming traffic volume as well as the incoming traffic that is destined for these nodes. In order to enable recoverability of the incoming traffic, if a node is in the Sleep state of in no connectivity range, then the multimedia traffic is cached using the promiscuous caching concept applied onto intermediate nodes in the path. The traffic-aware resource sharing scheme expands a cross-layer interaction (see Figure 3) for Level 2 Medium Access Level (L2/wireless MAC sleep/active time manipulation) and L3 using the proposed routing methodology. In the proposed middleware there are no strict associations among the tasks and the layers. The traffic-aware middleware enables the data packets to be traversed and manipulated through the utilized Data Link, Network, and Transport layers by considering the traffic awareness mechanism and the model for volume estimation to be reflected on these layers. The proposed traffic-aware mechanism evaluates (after the bootstrap process of the system) the estimated (quantified as Volume/Capacity) multimedia traffic that is destined for each node. In this way it enables –through the proposed mechanism- estimation for the next slot Sleep duration of the node as presented in the next section. In essence, the proposed mechanism
enables the efficient multimedia services by minimizing the end-to-end delay, while it allows promiscuous buffering in intermediate nodes by measuring the limitations over time, for each one the transmissions. Moreover, as the primary goal of the QoS for multimedia services is to provide priority, including dedicated transmissions of certain peers that serve as a buffering nodal points, parameters such as the jitter and latency (real-time and interactive traffic) should be significantly improved and kept under control. However, by providing priority for selected data flows the proposed mechanism does not cause the failure of other flows provided that neighboring nodes can host data multimedia packets for specified destination nodes for a specified amount of time. The framework in-focus takes into consideration the above estimations and through the volume of the traversed nodal traffic, it uses a model to estimate the next sleep-time duration of the destination node.

The power control is provided by determining the transmit periods and the associated power level such that the energy consumed is steadily reduced. To this end, by using the Backward traffic-aware mechanism presented in the next section, the scheme aims to guarantee the resource sharing stability, whereas at the same time to offer energy conservation. Since nodes in wireless networks typically rely on their battery energy, the proposed framework encompassed in a traffic-aware middleware, utilizes a reflective mechanism which hosts a traffic-aware scheme for conserving energy in CR wireless environments. The scheme evaluates the scheduled activity periods of each node, in order to measure and estimate a ‘safe’ forecast time duration for the scheduled time that each node can safely sleep in order to conserve energy.

The input nodal traffic is being considered in this work and estimated according to the Backward Traffic Difference (BTD). Wireless nodes, either if they are acting in the network as intermediate forwarding nodal points or as destinations, they have to be self-aware in terms of power and
processing as well as in terms of accurate participation in the transmission activity. There are many techniques such as the dynamic caching-oriented methods [11]. The present work utilizes a hybridized version of the proposed adaptive dynamic caching [31] which is considered to behave satisfactorily and enables simplicity in real time implementation [11]. The performance of message delivery in devices communicating in a Mobile Peer-to-Peer (MP2P) manner depends on two essential aspects: the traffic volume and the impact on the devices’ lifespan, and the mobility. Therefore it is important to consider the traffic factor and enable, through the applied F-BTD scheme, a reflective action on the sleep-time duration of the node(s). The following section presents the related estimations, where according to the incoming traffic, each node evaluates the next sleep-time duration by using the F-BTD.

3.3.1 Selective Fibonacci-based Backward Difference Traffic estimation for Energy Conservation for delay sensitive multimedia transmissions

Taking into account the fact that opportunistically connected nodes are changing their operational characteristics dynamically, when a source needs to send requested packets or stream of packets (file) to a destination where the destination node(s) may have moved or is/are set in the sleep-state, then the requested information will be missed and lost. For this purposed a promiscuous caching mechanism is proposed [32] where nodes can passively cached/buffer their missed data packets/chunks onto intermediate nodes in the end-to-end path. However, the ‘cached’ traffic was never considered to examine in which degree the volume of this traffic can be used to impact the sleep-time duration of the node during the next sleep-time cycle. Within this context this work proposes the F-BTD where the volume of the cached traffic is considered in order to define the different Fibonacci traffic moments. The activity period(s) of a node is primarily dependent on the nature and the spikes of the incoming multimedia traffic destined for
this node [32]. If the transmissions are performed on a periodic basis then the nodes’ lifetime can be forecasted and according to a model can be predicted and estimated [33]. However, this is not the case for examination in this work.

Each node admits multimedia traffic while in the active state, whereas if the node is in the sleep-state it can cache the multimedia traffic onto the 1-hop neighbour node \((\text{Node}(i-1))\) shown in Figure 4. As a showcase this work takes the specifications of the IEEE 802.16e [34] that are recommending the duration of the forwarding mechanism that takes place in a non-power saving mode lays in the interval \(1 \text{nsec} < \tau < 1 \text{psec}\). This means that every \(~0.125\mu\text{sec}~(8\text{ times in a msec})\) the communication triggering action between nodes may result a problematic end-to-end accuracy. Adaptive Dynamic Caching ([31] and [35]) takes place and enables the packets to be “cached” in the 1-hop neighbouring nodes. Correspondingly, if node is no-longer available due to sleep-state in order to conserve energy (in the interval slot \(T=0.125\mu\text{sec}\)), then the packets are cached into an intermediate node with adequate capacity equals to: \(C_{i,j,k(s)}(t) > C_{i,j,i}(t)\), where \(C_{i,j} > \alpha \cdot C_{i}\); where \(\alpha\) is the capacity adaptation degree based on the time duration of the capacity that is reserved on node \(N\) of \(C_k\); where \(C_{i,j,k(s)}(t)\) is the needed capacity where \(i\) is the destination node and \(k\) is the buffering node (a hop before the destination via different paths).
Figure 4. A schematic diagram of the promiscuous caching mechanism addressed in this work

This scheme is entirely based on the aggregated self-similarity nature of the incoming multimedia traffic by associating the different traffic moments and the volume of incoming traffic to increase or decrease the next sleep-time of each node accordingly. This adaptive mechanism is achieved by using the F-BTD shown in the next section.

3.3.2 Selective Fibonacci Backward Difference Traffic Moments and Sleep-time duration estimation

Let $C(t)$ be the capacity of the traffic that is destined for the Node $i$ in the time slot (duration) $t$, and $C_{N_i(t)}$ is the traffic volume capacity that is cached onto Node $(i-1)$ for time $t$. Then, as shown in Figure 5 according to the one-level Backward Difference of the Traffic, the difference in the capacity measure can be estimated as the difference of the traffic while the Node$(i)$ is set in the sleep-state—and admits traffic- for a period, as follows:

$$F_{N_i(3)} \left[ T(\nabla C_{N_i(1)}) = T_2(\tau) - T_1(\tau - 1) \right]$$

$$F_{N_i(4)} \left[ T(\nabla C_{N_i(2)}) = T_3(\tau - 1) - T_2(\tau - 2) \right]$$

$$\vdots$$

$$F_{N_i(i+n+3)} \left[ T(\nabla C_{N_i(n+1)}) = T_n(\tau - (n-1)) - T_{n-1}(\tau - (n-2)) \right]$$ (1)
where $\nabla C_{N_i(i)}$ denotes the first moment traffic/capacity difference that is destined for $Node(i)$ and it is cached onto Node $(i-1)$ for time $\tau$, $T_2(\tau) - T_1(\tau - 1)$ is the estimated traffic difference while packets are being cached/buffered onto $(i-1)$ hop for recoverability.

Equation (1) depicts the BTD estimation for one-level traffic comparisons, denoting that the moments are only being estimated for one-level ($T_2(\tau) - T_1(\tau - 1)$).

The associated Fibonacci Backward Difference Traffic moments can be evaluated by using the aggregated traffic of the $\nabla C_{N_i(i-1)}$, $\nabla C_{N_i(i-2)}$ for the $\nabla C_{N_i(i)}$ where it stands that:

$$F_{N_i(n)} = T(\nabla C_{N_i(i-1)}) + T(\nabla C_{N_i(n-2)}), \forall N_i(t) < t_s \quad (2)$$

where $t_s$ is the upper allowed end-to-end delay for the $s$ stream for adequately reaching the destination, and $N_i(t)$ is the time that the specific packet chunks were cached onto the
intermediate node. \(F_{N_i(n)}\) is the Fibonacci Backward Difference Traffic moments (Figure 5) for the two previous BTD moments \(\nabla C_{N_i(n)}\) and \(\nabla C_{N_i(n-2)}\). Equation 2 is valid only if the F-BTD is greater than the next pair BTD evaluation as follows:

\[
F_{N_i(n)} > F_{N_i(n+1)}
\]  

(3)

Let \(t\) be the duration function that node \(i\) should be in active-period, then the sleep-time duration can be measured using the following expression:

\[
T_s(i) = \frac{t(C_{N_i(t-1)}) + t(F_{N_i(t)})}{1 + \Delta T_s}
\]

(4)

where \(T_s(i)\) is estimated sleep-time of the node during the next cycle, \(t(C_{N_i(t-1)})\) is the time that the \(C_{N_i(t-1)}\) capacity of traffic needs to be processed, and \(t(F_{N_i(t)})\) is the F-BTD if the Eq. 4 is satisfied. The \(\Delta T_s\) is measured according to the:

\[
\Delta T_s = \frac{a_i(\tau)}{t_s} + T(\nabla C_{N_i(n)})
\]

(5)

where \(\nabla C_{N_i(n)}\) is the normalized BTD, \(a_i(\tau)\) is the incoming traffic for node \(i\) during the (current) time \(\tau\) and \(t_s\) is the upper allowed end-to-end delay for the \(s\) stream for adequately reaching the destination. In the case where Eq. 4 is not satisfied, the sleep-time duration of the node is measured according to the following:

\[
T_s(i) = \frac{t(C_{N_i(t-1)})}{1 + \Delta T_s}
\]

(6)

The above measures are taking place according to the algorithmic steps in Table 2.

for Node(i) that there is \(C(t)>0\) in the best path in k intermediate nodes
while \((C_{N(i)} > 0)\) \{ //cached Traffic measurement

Evaluate \((T(\nabla C_{N(i)}))\);

if (Activity_Period for node(i)>0 \&\& C_{N(i)} \forall t(N_i) > 0 )

//Measure Sleep-time duration

Evaluate \(\nabla C_{N(i)}\) and \(\nabla C_{N(2)}\);

if \((N_i(t)<t_s)\)

estimate the \(F_{N_i(s)}\) such that \(F_{N_i(s)} > F_{N_i(s-1)}\)

sleep for \(T_s(i)^w = \frac{t(C_{N_i(s-1)}+t(F_{N_i(s)}))}{1+\Delta T_s}\); //during the next cycle

else

sleep for \(T_s(i)^w = \frac{t(C_{N_i(s-1)})}{1+\Delta T_s}\); //during the next cycle

\} //while

\} //for

---

**Table 2. Basic steps of the proposed BTD scheme**

The delay that the transmission experiences \(\delta_y\) should satisfy the \(\delta_y < d_p\), where \(d_p\) is the maximum delay in the end-to-end path from a source to a destination and can be is evaluated as:

\[
d_p = \sum_{i=0}^{i-1} \delta_i + T_i \forall (\delta_i + T_i) < t_s
\]

(7)

where \(\delta_i\) is the duration where the requested data was hosted onto \(i\)-node, and \(T\) is the transmission delay.
Taking into consideration the above estimations, the Energy Efficiency \( EE_{i,j} \) can be defined as a measure of the capacity of the Node(\( \text{Node}(i) \)) over the Total Power consumed by the Node, as:

\[
EE_{i,j}(T) = \frac{C_{i,j}(T)}{\text{TotalPower}} \forall \min(T_{i,j})
\]  

Equation 8 above can be defined as the primary metric for the lifespan extensibility of the wireless node in the system.

### 4. Performance evaluation analysis, experimental results and discussion

Several experimental tests were conducted, in order to validate the efficiency of the proposed routing protocol and the resource intensive traffic-aware scheme. Performance evaluation results were extracted, by conducting exhaustive simulation runs and experimentation using the NS-2 [36] and the generated real traffic traces for implementing the proposed scenario. The energy consumption model used in the simulation for the calculation of the amount of energy consumed is based theoretically on the specifications of the WiMax IEEE 802.16e (ver. 2005) [34]. The extracted results are characterizing the trade-off issues between the performance in deploying the discussed scenario and the Energy consumption of each secondary CR node by using the proposed traffic-oriented scheme. Results also encompass comparisons with other existing schemes for the throughput, the reliability and the accuracy offered by the proposed framework as well as EC efficiency conveying an estimated confidence interval (CI) of approximately 3%<CI<5%. All confidence intervals were found to be less than 5% of the mean values of the certain examined parameters. The mobility model adopted in this work is based on the probabilistic mobility scenario derived by Fractional Random Walk. The probabilistic random walk mobility model was derived from the Brownian motion [37], where nodes are moving according to certain probabilities with respect to the location and the time.
According to such simulation scenario, a number of data flows are contending to pass through the same intermediate node, thus evaluation of delay metrics is crucial, for an efficient performance of the proposed routing protocol. In this context, a number of delay metrics [38], are evaluated, such as end-to-end delay, backoff delay, switching delay and queuing delay. End to end delay from the source node up to the destination node is computed as the overall sum of queuing delay and node delay:

\[ D_{End-to-End} = D_{queing} + D_{node} \]  

(9)

Node delay at an intermediate node \( i \) is based on switching delay and backoff delay and is computed as follows:

\[ D_{node} = \sum_{i} (D_{switching} + D_{backoff}) \]  

(10)

A dynamic topology model was used and nodes are utilizing the Fractional Random Walk where the BTD and F-BTD is applied. A common look-up application is being developed to enable users to share resources on-the-move that are available by peers for sharing. This application hosts files of different sizes that are requested by peers in an opportunistic manner. Each device has an asymmetrical storage capacity compared with the storages of the peer devices. The ranges of the capacities for which devices are supported are set in the interval 1MB to 20MB\(^1\).

Figure 6 represents simulation results related with the performance comparison of mean end-to-end delay, while the number of active flows is increasing for both version of the proposed routing protocol. It is clear that when routing protocol incorporates the assigning mechanism and the number of active flows in the network is small, there is no important advantage, in terms of mean end-to-end delay. However, when the number of active flows is more than three, intermediate nodes begin to suffer the accumulating queue, and flow redirection becomes necessary. Such results also show that the mean end-to-end delay is less, in the

\(^1\) The capacity for each device can be tuned according to the volume of the traffic in the configuration process.
case of the enhanced routing protocol, in comparison to the basic version of it without incorporating the assigning mechanism, supporting the efficient provision of delay-sensitive multimedia streams over cognitive radio networks.

Figure 6. Mean end-to-end delay for different number of simultaneous flows

Figure 7. End-to-End Delay for the 1st flow versus probability of PU presence
Figure 7 depicts simulation results of end-to-end Delay for one single flow, when the probability of primary user’s presence increases, while Figure 8 presents the average end-to-end Delay for ten simultaneous flows for a certain value of primary user’s presence probability. From both figures it is clear that when the probability of primary user presence is getting higher, delay is increasing, while in the case of the basic routing protocol, delay increase is more significant in comparison to the enhanced routing protocol incorporating the assigning mechanism. This result is reasonable, since the probability of the presence of an incumbent system is detected as a route failure, introducing in this way additional delay.

Figure 9 presents the average end-to-end delay that occurred among the source and destination nodes as the distance between them is increased. From this figure it is clear that the distance affects the delay among nodes. This result is reasonable since the longer is the routing path, the more numerous are the primary nodes that affect the path, and the more significant are the effects of the route range/diversity. It is further observed that the initial version of the proposed routing protocol adds higher delays, as the distance is increasing rather than those occurred when
assigning mechanism is introduced, resulting the most optimal routing paths between the source and destination nodes. Consequently, the longer is the path, the more significant are the effects of the route diversity. In addition, Figure 10 depicts the comparison among both versions of the proposed routing protocol, under the number of hops that are required, in order to make feasible all routing paths between source and destination nodes, for each flow set according to the simulation scenario. This comparison results that routing protocol, incorporating the assigning mechanism performs better, since it makes the decision for routing path establishment at every hop.

Figure 9. Average end-to-end Delay versus node distance
In this section, we demonstrate the effectiveness of the proposed BTD approach and validate the accuracy of the developed scheme by comparing the analytical results of the scheme to those obtained from extensive simulation experiments in work done in [8] and [11]. In Figure 11 the network lifetime in contrast to the number of mobile nodes for different schemes is presented. It is important to notice that the network lifetime is significantly extended by using the proposed F-BTD for offering energy conservation. In turn Figure 12 shows the average Throughput in contrast to the number of nodes during the resource exchange process for different schemes. It is undoubtedly true that the proposed scheme enables higher average Throughput response in the system by using the selective F-BTD scheme.
**Figure 11.** The average Throughput with the number of nodes in the cluster zone for delay bounded transmissions. Evaluation takes place for different comparable schemes.

**Figure 12.** The Average Throughput with the number of nodes during the resource exchange process for different schemes.
Figure 13. The Average Throughput with the Total Transfer Delay (μsec)

Figure 14. Lifespan of each node with the number of hops using different schemes under Real-Time evaluations

Figure 13 shows the Average Throughput with the Total transfer delay in (μsec) for different mobility degrees. The different Throughput responses are shown in contrast to the mobility characteristics, for full node mobility, moderate and low (>30%) mobility. Figure 14 shows the
lifespan of each node with the number of hops for different schemes evaluated in real-time. Figure 15 shows the average energy consumed with the power ratio in decibels (dB) of the measured power referenced to one mW while Figure 16 shows the fraction of the remaining Energy through time for different schemes. Results obtained in Figure 16 show that the network lifetime can be significantly prolonged when the F-BTD is applied. By comparing the results obtained for the generic BTD scheme developed in [11] as well as with the periodic sleep/wake scheduling, obviously the proposed scheme offers greater Energy-Efficiency, while it minimizes the delay per request.

Likewise, Figure 17 shows the respective Complementary Cumulative Distribution Function (CCDF) with the Mean download Time for requests over a certain capacity. The later evaluation was extracted in the presence of fading and no-fading communicating obstacles. Results obtained and presented in Figure 18, show the CCDF sharing reliability with the number of sharing peer-users. The results for CCDF sharing reliability with the number of sharing peer-users, were extracted by conducting both simulation experiments and evaluations in the presence of fading and non-fading characteristics. Comparative results extracted by simulation and compared with existing schemes, exhibit similarities in the measured values with the associated optimization variations (which is measured within the confidence interval of 5-7% for the conducted experiments).
Figure 15. Average energy consumed with the power ratio in decibels (dB) of the measured power referenced to one mW.

Figure 16. The fraction of the remaining Energy through time using real-time evaluation for different schemes.
Figure 17. The CCDF for the Sharing Reliability with the Mean download Time for requests below a certain capacity

Figure 18. CCDF Sharing Reliability with the Number of sharing Peer-users
Figure 19. Energy Efficiency (service capacity/total energy consumed) bytes/mW with fraction of the remaining energy onto each node

The Energy Efficiency (bytes/mW), which is defined as the service capacity/total energy consumed as in Eq. 8, with fraction of the remaining energy onto each node is shown in Figure 19, for 4 different schemes. The proposed framework is shown to have the higher remaining energy for each node in the system whereas, compared to the scheme in [8], it is shown to have an optimized Energy-Efficiency behaviour as it allows greater Energy-Efficiency in contrast to the remaining Energy of each node.

5. Conclusions and further research

In order to guarantee the end-to-end availability of requested multimedia resources, as well as significantly reduce the energy consumption and maintain the requested scheduled transfers, a dynamic adaptive methodology is needed. This chapter presents an efficient routing mechanism where, in collaboration with the underlying F-BTD scheme, it enables energy conservation and reliable data flow among secondary communication nodes with heterogeneous spectrum
availability in CR systems, while it fulfils the delay constraints and requirements by multimedia resources. The proposed adaptive traffic-oriented mechanism takes into consideration the active moments, and measures the incoming traffic by using the selective F-BTD scheme. The supported undelaying routing scheme establishes an end-to-end optimal path whereas, secondary nodes in CR systems can efficiently and, in a collaborative manner, share requested data/resources. The F-BTD scheme enables the self-tunability of the sleep schedule of each node, whereas it is applied through the traffic difference of the active moments of the traffic, measured within a certain transmission time-frame. Within the proposed framework, the bounded end-to-end delay of the transmission is taken into consideration for each secondary node, aiming to impact the EC through the modelled traffic-aware mechanism. The performance evaluation through simulation shows that the proposed routing scheme in collaboration with the F-BTD mechanism, manipulates the energy consumption of each secondary node/device effectively, and outperforms in contrast to similar traffic-aware schemes. Moreover, the traffic-aware management scheme can significantly reduce the energy consumed and can keep the throughput response of the system at relatively high-levels. The comparative measurements with other similar traffic-oriented and other periodic schemes show that the proposed methodology can efficiently conserve the energy, by offering at the same time significantly high SDRs, and can significantly extend the lifetime of each secondary node in the CR network. Furthermore, efficient routing protocol operation, as a matter of maximum-possible routing paths establishments and minimum delays was validated, by adopting the proposed message exchange mechanism that was developed based on the simulation scenario defined above. Towards evaluating the performance of the routing protocol in this respect, a large number set of experimental tests was conducted under controlled simulation conditions, where various
secondary systems were concurrently/simultaneously communicating in ad-hoc connections, accessing the available TVWS. The obtained experimental results verified the validity of the proposed routing mechanism, towards enabling for an efficient communication among secondary nodes located in areas with different TVWS availability.

Further streams in our on-going research include the evaluation of our scheme using real-time measurements and real-time verification using the existing infrastructure. Issues to be considered are the topology formation, using social collaboration as well as geographical profiles, in order to face potential partitioning problems. Moreover, the usage of traffic engineering models, in order to explicitly express the behaviour of such dynamically changing scenarios. Additionally we are working towards the expression of our scheme with the combined infinitesimal perturbation analysis and apply a stochastic algorithm into the performance gradient of the system. Moreover, within the current research context will be the expansion of this model into a Multi-level Markov Fractality (MMF) model so that it associates the different moments of the active traffic for enabling energy conservation. Finally, several optimization methods will be adopted, towards minimizing delays occurred during the routing paths of data flows and maximizing the number of established paths. This comprises an open-end research issue with many research concepts for future examination.

6. Acknowledgments

The research of this chapter is funded through the Operational Program “Education and Lifelong Learning”, Action Archimedes III and is co-financed by the European Union (European Social Fund) and Greek national funds (National Strategic Reference Framework 2007 - 2013).
References


