Cognitive Spectrum Handover Technology

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Abstract:
Based on spectrum sensing, dynamic spectrum allocation and reconfiguration technologies in Cognitive Radio (CR), this paper fully considers the matching issues between short-term spectrum characteristic and service characteristic. In the communication process, the network-side selects switch terminals to initiate handover command to solve problems due to limited capacity of the system, such as overload and new session decline, improving the success rate of switching on the premise of ensuring user's QoS, reducing blocking probability with more session admission, eliminating overload, increasing system throughput, and improving the whole system performance.

1 Research Background

The radio spectrum is a precious and limited resource that is allocated and authorized for use by the state authorities. Usually one frequency band is used for long term by one wireless communication system exclusively, and therefore, different wireless communication systems use different frequency bands, and no interference is produced in between.

However, the spectrum resource is becoming increasingly scarce because the spectrum-based services and devices are growing markedly as a response to the rapidly developing wireless communication. With the static spectrum management approach, the spectrum is allocated in the first place for long-term authorized use and the authorized system capacity is invariable and limited. In some frequency band, the service comes in great volume as most mobile terminals using the network resource can only use the services (voice and data) on the band allocated to its system. With the growing terminal number, the system suffers from frequent overload which will inevitably result in downgraded performance of network service and hence lowered user satisfaction. This is a problem to be solved by all present network operators. On the one hand, although some technologies, for example, admission control[1], load balancing[2] and frequency hopping[3], are introduced as an attempt to eliminate the overload, the conventional spectrum allocation policy is still producing the bottleneck of network performance. This is because when the system capacity is of an invariable value, the number of users to be carried by the network can easily reach the upper threshold. On the other hand, the spectrum resource is also wasted as some other frequency bands stay unused for most of the time. The traffic of communication in a radio system changes with the time and place, but the spectrums of most current radio systems are allocated in light of the peak-hour traffic, hence the waste of the spectrum resource at non-peak hours, which are not made full use of.

The idea of spectrum sharing based on Cognitive Radio (CR) was first proposed by Joseph Mitola[4]. The CR technology makes it possible to flexibly use the spectrum resource anytime and anywhere. It is widely deemed to be the optimal solution to the low utilization of wireless spectrums and can ease the conflict between growing wireless services and increasingly scarce spectrum resource. The technology will not only change the work mode (from manual configuration to intelligent control) of the wireless communication system, making the system one part of market economy instead of planned economy, but also change the management mode of the current wireless network and the spectrum management regulations and rules as well. Meanwhile, the technology is posing new challenges for device manufacturers, service users and network operators.

To make efficient use of the spectrum resource, the dynamic spectrum allocation technology[5] is introduced so that less precious spectrum is are wasted. The research work covers both technological and economical issues. The technological issue includes a series of additional technologies needed to perform dynamic spectrum allocation, for example, spectrum sensing technology [6-8], interference suppression technology[9-11] and power control technology[12-13]. The economical issue refers to the way the economic returns related with a spectrum allocated between the spectrum owner and user in

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the process of dynamic spectrum management. This would involve the spectrum allocation algorithms and mechanisms, for example, the auction algorithm and spectrum leasing mechanism[14].

Under this development trend, both the terminals and network devices should be able to reconfigure[15], that is, they should support the conversion from a working frequency to technical parameters so that they will be able to use more wireless resources than what the conventional spectrum allocation could provide them with. Besides, the implementation of reconfiguration technology makes it flexible and simple to perform dynamic and fast frequency allocation and spectrum handover within a cell (a single base station). Meanwhile, the former un-reconfigurable mobile terminals will coexist with the reconfigurable mobile terminals for a quite long time while the technologies evolve and even though the terminals support reconfiguration, its service types need to set some requirements on the characteristics of the target frequency of handover.

With the above technology employed, the system can, on the one hand, obtain short-term leased spectrum through inter-network negotiation, and on the other, detect the spectrum holes with the CR technology and accesses available spectrums when the chance comes so as to have the system capacity replenished. The existing dynamic spectrum allocation approach is used to dynamically allocate the frequencies only when there is no interference, without addressing the issue of frequency use after the allocation. With the current technology scheme, however, the use and management of the spectrum resource are performed on the basis of known and long-available spectrum resource information. The use of temporarily available resource differs markedly from that of the resource allocated for long-term and invariable use. This is because the newly allocated resource is make-shift and heterogeneous, especially the acquisition of the spectrum resource information, as the resource obtained by way of spectrum sensing is short-term and unstable, is also incomplete and

uncertain. Because the spectrum handover will bring in some delay and affect the network structure, the QoS of applications should be guaranteed as much as possible during the process of spectrum handover. As the current system is concerned, most user terminals (including hardware and software) do not support other frequency bands and therefore the available spectrum resources can be useless for them. Even if the terminals (including hardware and software), moving speed and bandwidth meet the conditions of spectrum handover, some services are not suitable for the frequencies because the frequencies are make-shift and unstable and therefore not good enough for the QoS requirements of those services. If a handover is forced in this case, call drops and other unwanted faults will be produced as a result. To conclude, the first problem to be solved is to make use of the newly obtained spectrum resource, to allow more user accesses and boost system throughput.

In the scenario of single cells of wireless communication system, the system capacity will be exhausted with growing users and hence the overload of system and refusal of new sessions. To solve this problem caused by limited system capacity, this paper proposes a cognition-based spectrum handover approach that makes use of the spectrum sensing, dynamic spectrum allocation and reconfiguration technologies and takes into full consideration the features of short-term frequency and service features. With this approach, the handover success rate is expected to be enhanced, the blocking rate to be lowered and performance of the communication system to be improved with guaranteed user QoS.

2 Cognition-Based Spectrum Handover

Suppose the system is available with its own invariable frequency allocated for long-term use, the base stations and some terminals support the function of frequency reconfiguration, and the detectable frequency resource is sufficient. In the scenario of single cells, when the system load exceeds a certain threshold, the system obtains short-term available spectrum resource to ease the load pressure, replenish system capacity and realize dynamic allocation of spectrum resource through inter-network negotiation and resource leasing, or sensing of spectrum holes by terminals. However, the frequency resource acquired by way of dynamic spectrum allocation is make-shift and the resource information is incomplete, uncertain and unstable. Also if the resource is acquired through spectrum sensing, a system authorized for the resource can take up the resource at any time and this means that the system accessing the make-shift resource at a secondary chance has to get ready for a handover to another idle frequency at any time. In other words, a bunch of new problems may arise from using the newly allocated short-term resource. For example, whether the terminals support the frequency, whether the service type matches the frequency features, that is, whether the service can be carried on the frequency band, and what the different resource reallocation flows resulted from the time effectiveness of the spectrum are. To prevent these problems and possible call drops after a handover, when a terminal is selected for the spectrum handover, some issues should be taken into consideration. These issues include: the hardware and software re-configurability of the terminal, service bandwidth and moving speed, whether the type of service carried by the terminal is suitable for the features of the target frequency. Since common non-reconfigurable mobile terminals cannot use new spectrum resource and thus spectrum efficiency cannot be improved in this respect, it is unnecessary for the new resource to wait for new sessions. Instead, the reconfigurable mobile terminal with live sessions in the original frequency band can be selected to adapt to and handed over to the new spectrum resource. In this way, the handover success rate can be improved and the original authorized frequency band can admit more common non-reconfigurable mobile terminals, hence the higher system capacity and throughput.

2.1 Features and classification of spectrum resource

By different features, the spectrum resources available on network side come in three types:

(1) Inherent long-term spectrum resource of system

Such spectrum resource is allocated invariably, available for long-term stable use, and with complete information.

(2) Leased spectrum resource

Such spectrum resource is acquired by way of purchasing, leasing or network negotiation. It is dynamically allocated, available for short terms, stable and with complete information.

(3) Sensed spectrum resource

Such spectrum resource is acquired through spectrum sensing. It is dynamically allocated for chance access, available for short terms, unstable and with incomplete information.

Both type (2) and type (3) are short-term spectrum resources whose features can be indicated with statistical parameters. The statistical parameters are as follows:

(1) Availability

It indicates whether the resource is currently available or not, including: whether the spectrum is idle and allows for chance access, how good the spectrum quality is (frequency features, signal-to-noise ratio) and what the price of the spectrum is.

(2) Duration of availability

It indicates the duration of leased use of the leased spectrum resource, and the available duration with a certain probability of the sensed spectrum resource.

(3) Stability

It indicates the continuous stableness of the resource. It is a function of the available duration and it can be expressed with the two-state Markov process.

Different sensed spectrum resources can be sequenced by the available duration.

2.2 Features and Classification of Service

There are four major service types in the present wireless communication system: conversational service, streaming service, interactive service, and background service. The four types have many different requirements on the transmission delay. The conversational service and streaming service are delay-sensitive, while the interactive service and background service are not very sensitive to delay.

Parameters for describing the service features are as follows:

- Delay requirement
- Estimated service duration
- Service bandwidth

Different user terminals carry different service types, which come with different requirements on the delay (DL_i, $i=1\cdots K$ ms). DL_i reflects the requirement of a service type on spectrum stability. By different delay requirements, the services are classified and adapted to the spectrum resource. Namely, the smaller the DL_i is, the more stable the frequency is required to be, and the service is more suitable for the spectrum with complete information and in very stable status. For example, the

delay-sensitive services (conversational and streaming services, for instance) will be selected and handed over, with preference to the short-term highly-stable spectrum with definite information as indicated in the list of available frequencies. But the delay-insensitive services (interactive and background services, for instance) will be selected and handed over to the short-term spectrum with uncertain information that is comparatively stable.

For service types that do not require highly stable frequency, the service duration is estimated and then the services carried by the terminal are sequenced by their duration.

2.3 Resource Adaptation

Various factors are involved in resource adaptation. The factors include but are not limited to the following:

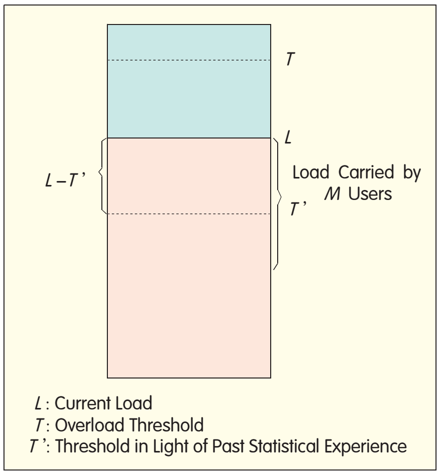
- The service delay requires to adapt to the stability feature of the short-term spectrum
- The estimated service duration adapts to the available duration of the short-term spectrum
- The service bandwidth requirement adapts to the capacity of the short-term spectrum resource

Φ is delay requirement threshold/frequency stability requirement threshold, which is adjustable.

First, the target handover resource is selected according to different delay requirement so that the service-carrying terminal is directed to different types of short-term spectrum resources.

When $DL_i < \Phi$, the type of service is adapted during the handover process to the leased spectrum.

When $DL_i \geqslant \Phi$, the type of service is



▲Figure 1. System load container for single cells.

adapted to the sensed spectrum during the handover process.

For a terminal whose target handover resource is the leased spectrum, the process of spectrum leasing is initiated in light of the needed capacity and estimated service duration and then the leased spectrum that meets the capacity requirement and leased duration requirement is selected.

The spectrum obtained from spectrum sensing is usually applied for carrying the delay−insensitive services. If possible, the terminal with long estimated service duration (Tu_i) is handed over to the target spectrum with long statistical interval (that is, the available duration of spectrum, indicating the spectrum stability), till the spectrum cannot be allocated with more service bandwidth. That is to say, the following formula is satisfied:

$$\sum_{i=1}^{n} b_i \leqslant B_{fj}, i=1\cdots n, j=1\cdots C$$

Where, b_i is the bandwidth for the terminal i to carry services; B_{fj} is the capacity of the frequency f_j configured for a base station; and C is the number of frequencies (enough for handover) for sensed spectrum resource configured for the base station.

2.4 Spectrum Handover Flow

If the load of a cell exceeds the threshold, terminals will be selected for handover to the spectrums whose features match the service type of the terminals.

Because the spectrum leasing process involves economical issues and inter−network negotiation, the spectrum resource obtained through spectrum sensing instead of spectrum leasing is used if a chance access is possible. This applies to terminals whose service types are delay−insensitive and the number of handovers can ease the overload.

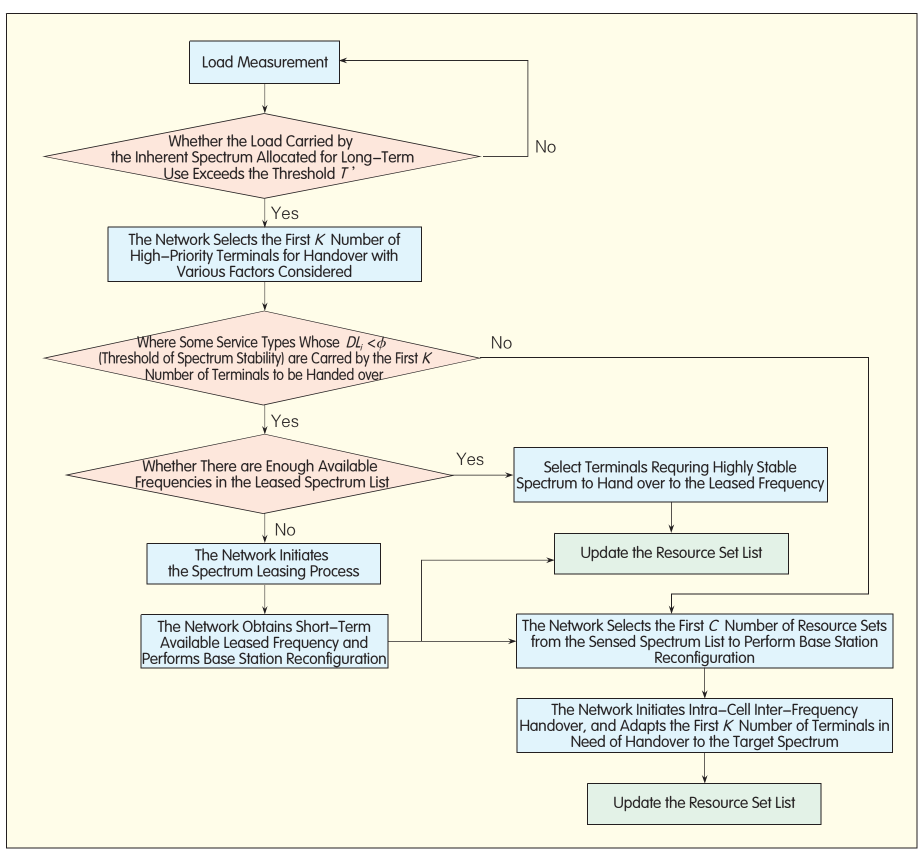
The process of spectrum leasing should be initiated for the delay−sensitive services with low *DL*, which are not suitable (as call drops will be produced) for the unstable short−term spectrum resource obtained through spectrum sensing. The short−term stable spectrum with complete information is leased in this case. However, for services not very sensitive to delay, the service duration is estimated, and then the terminal is adapted to the sensed spectrum with long available duration.

The whole handover flow comprises two parts: First, the resource adaptation and handover process initiated on the network side when the load exceeds the threshold *T*'; Second, the handover process initiated on the network side when the short−term spectrum resource expires or is otherwise unavailable.

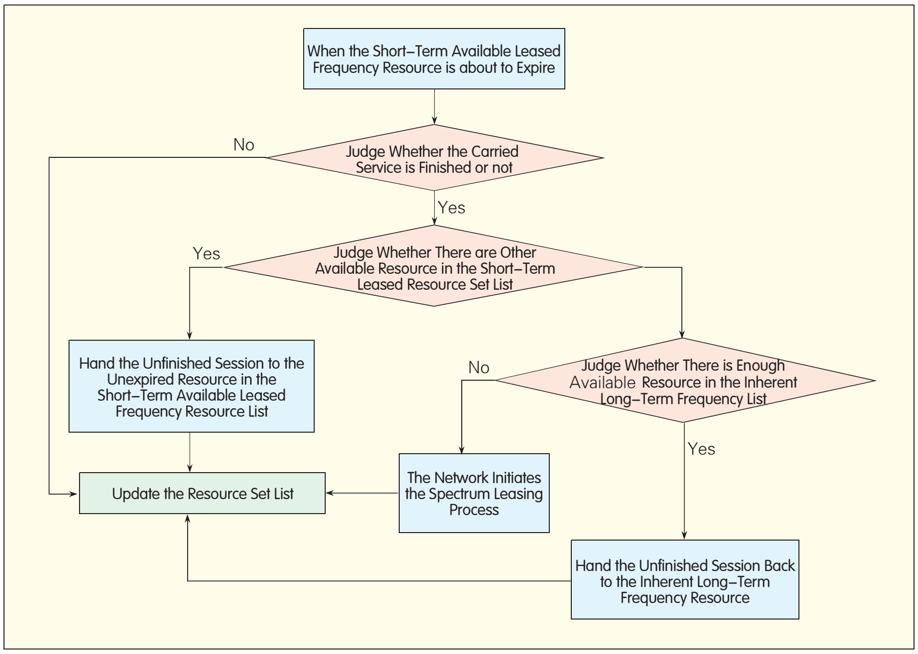
For new arrived sessions, the admission control process is implemented only on the inherent long−term spectrum resource.

The schematic diagram in Figure 1 shows a container of system load for single cells. In the figure,

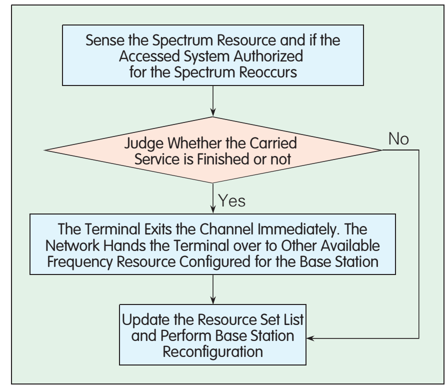
- *T* refers to the overload threshold. That is, if the load exceeds this threshold, the system is overloaded.
- *T*' refers to the threshold set in light of past statistical experience. The system stays in optimal status under this threshold.
- *L* refers to the current load, which can be indicated with bandwidth.
- *M* refers to the number of users that support handover. With the information reported by terminals, including terminal's reconfiguration ability, delay requirement, bandwidth need, and moving speed, the users are sequenced by delay sensibility with the least sensible ones put on top. The users with low delay requirement are selected first as the candidate terminals for handover. (A user who supports handover means that the user is



▲Figure 2. Flow of leasing initiation decision, reconfiguration and handover.



▲Figure 3. System flow when the leased spectrum resource is about to expire.



▲Figure 4. System flow when the system authorized for the sensed resource reoccurs.

reconfigurable, besides, it is not very sensible to delay and is moving quite slowly.)

Suppose N is the number of users with load of $L-T'$, K is the number of users expecting for handover, then $K=\min(N,M)=n_{DL_i}<\phi+n_{DL_j}\geqslant\phi$.

Figure 2 shows the flow of leasing initiation decision, reconfiguration and handover. Figure 3 shows the system flow when the leased spectrum resource is about to expire. Figure 4 shows the system flow when the system authorized for the sensed resource reoccurs.

3 Conclusion

The most fundamental difference in resource management between the cognitive wireless network and current network lies in the time–varying feature of the spectrum resource in the cognitive wireless network. To initiate handover and perform admission control in the cognitive radio network, this feature should be taken into consideration in a bid to find the rules in disorderly changes, guarantee basic QoS level, maximize system throughput, decrease system overhead and avoid the interference from authorized system. Furthermore, because the spectrum resources are heterogeneous, the research of admission control may consider user preferences and service features so that the users are allocated with suitable wireless resources, and the inter–layer design can be optimized.

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