Greedy Based Proactive Spectrum Handoff Scheme for Cognitive Radio Systems

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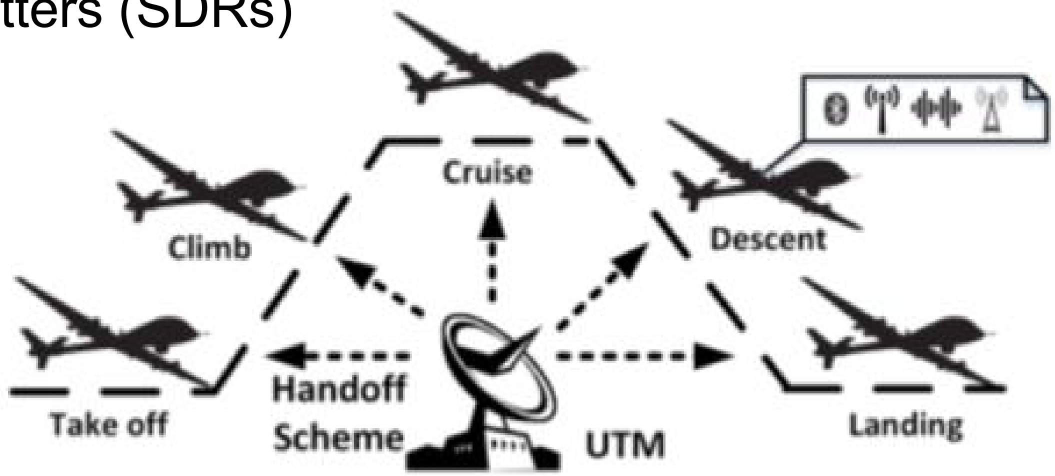
Scenario

Handoff for UAV Communication
- UTM based

- A2G communication
  - Receive handoff scheme from ground stations along with messages
  - Transmit messages following handoff scheme through multiple transmitters (SDRs)



Introduction

Handoff Solutions

- **Reactive** handoff -- without having knowledge of PU behaviour
  - Research: Shorten sensing time / period
- **Proactive** handoff -- based on prediction of PU model
  - Acquisition of PU models: Spectrum sensing & external RF resource e.g. (radio environment map), predictive methods, decision-making engine etc.
  - Output: Queue model (e.g. M/G/1), time for triggering deterministic system

TABLE 1: Comparison of spectrum handoff techniques.

Techniques	Strong point	Weak point	Handoff latency	Principal characteristics
Pure proactive handoff	(i) Predicts the arrival of PU on the channel (ii) Fastest response collision rate reduction	(i) Obsolete target channel selection (ii) Poor PU traffic detection leads to poor handoff results	Very weak handoff time	(i) Appropriate for large detection data (ii) Exploitable in a well-modeled PU network
Pure reactive handoff	(i) Target channel selected accurately	Slow response	Medium handoff time	(i) Appropriate for short detection time data (ii) Exploitable for normal CRNs
Hybrid handoff	(i) Fastest response (ii) Intelligent target selection	(i) Selection of the obsolete target channel (ii) Poor proactive spectrum detection results in poor spectrum handoff	Very weak handoff time	(i) Appropriate for short detection time data
Nonhandoff schemes	(i) Very low interference level of PU	Very high interference level of SU	Incredibly high latency	

Yawada, Prince Semba, and Mai Trung Dong. "Intelligent Process of Spectrum Handoff/Mobility in Cognitive Radio Networks." Journal of Electrical and Computer Engineering 2019 (2019).

Handoff Model

Handoff Concept

- **Demonstration**
  - Components: 2 CRs, PU traffic models or maps, channels
- **Assumptions**:
  a. Different CRs can not occupy the same spectrum opportunity.
  b. CRs can not switch channels before finishing the occupation of current opportunity.
  c. CRs can access the spectrum in the middle of spectrum opportunity.
  d. CRs cannot switch back and utilize the past spectrum opportunity.
  e. Latencies of spectrum sensing and spectrum probing are not considered.

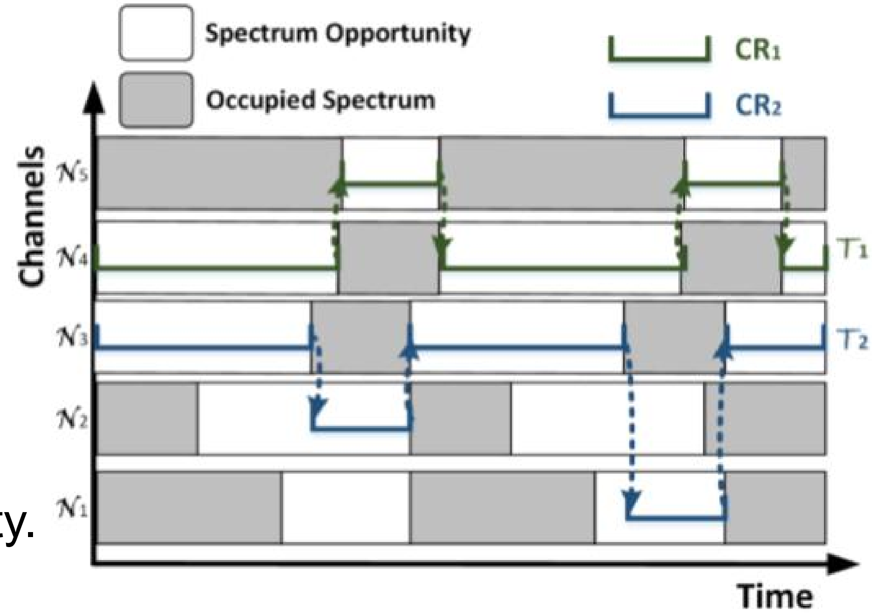


Fig. 2. Concept of handoff scheme

Handoff Model

QoS

- **Positive aspects**

  1) Opportunistic service time describes the duration of spectrum opportunity.
  2) Quality of channel describes degradation of signal quality that is based on a theoretical channel model.
  3) Available channels influence the number of vacant opportunities.
  4) Number of CR
  5) Probability of channel idle is derived from the confidence on the availability of each channel during the spectrum sensing period.
- **Negative aspects**

  1) Collision probability describes the chance that the channel can be accessed by other SUs interfering with each other.
  2) False alarm probability describes the accuracy of detection at the spectrum sensing stage.
- Power (Load) Control (Allocation concept)

Greedy Based Algorithm

Principles

- Channel allocation starts with selecting spectrum opportunity that is closest to the current opportunity in the time domain.
- Channels with poor QoS will be avoided in the handoff action.
- The spectrum opportunities with longer duration have more chances to be selected.

Objective Function

$$\Delta f_a(j|\mathcal{T}_a) = {T_d}^j Q^j P_i^j \lambda_{T_m}^{\Delta {T_m}_a^j} \lambda_c^{P_c^j} \lambda_f^{P_f^j} \lambda_n^{\tau(\mathcal{P}_a^j)}$$

Algorithm 1 Greedy Algorithm of Spectrum Handoff for MIMO System

```
J ← ∅, A ← ∅, W ← ∅
for a ∈ 𝒜 do
    𝒩_a ← 𝒯, 𝒯_a ← ∅
end for
while ∃ a ∈ 𝒜 and j ∈ 𝒩_a such that Δf_a(j|𝒯_a) > 0 do
    for a ∈ 𝒜 do
        j*_a ← arg max_{j∈𝒩_a} Δf_a(j|𝒯_a) //find maximum index
        ω*_a ← Δf_a(j*_a|𝒯_a) //keep the maximum value
    end for
    a*, j*_{a*} ← arg max_{a∈𝒜, j*_a∈𝒩_a} ω*_a(a, j*_a)
    ω*_{a*} ← Δf_a(j*_{a*}|𝒯_a) //find the overall maximum value
    Θ ← (1 − ε)ω*_{a*} //setting flexible threshold
    for a ∈ 𝒜 do
        if ω*_a ≥ Θ then //initially allocate the opportunity
            if j*_a ∈ J then //avoid collision
                if ω*_a > W(j*_a) then //allocate the opportunity to the CR with higher objective value
                    W ← W\W(j*_a), A ← A\A(j*_a)
                    W ← W ∪ {ω*_a}, A ← A ∪ {a}
                end if
            else//store handoff result
                W ← W ∪ {ω*_a}, A ← A ∪ {a}
                J ← J ∪ {j*_a}
            end if
        end if
    end for
```

Greedy Based Algorithm

Main Steps

- Initialisation
- Calculate objective function for each CR
- Set a flexible threshold
- Compare the objective functions with threshold
- Confilcts avoidence. (allocate the resource to the CR with bigger objective function result)
- Update parameters and save result

26: **for** $a \in \mathcal{A}$ **do**
27: **if** $a \in A$ **then** //CR_a is allocated to a opportunity
28: $\mathcal{T}_a \leftarrow \mathcal{T}_a \cup \{j_a^*\}$ //save the final handoff result
29: **for** $i \in \mathcal{A}$ **do**
30: $\mathcal{N}_i \leftarrow \mathcal{N}_i \backslash \{j_a^*\}$ //elimination
31: **end for**
32: **end if**
33: **end for**
34: $J \leftarrow \emptyset, A \leftarrow \emptyset, W \leftarrow \emptyset$
35: **end while**
36: **return** $\mathcal{T}_a \ \forall a \in \mathcal{A}$

Improvement

- Time based elimination (30)
- Time triggered loop (5)
- The closet opportunity is considered (7)

Experiment and Analysis

Conditions

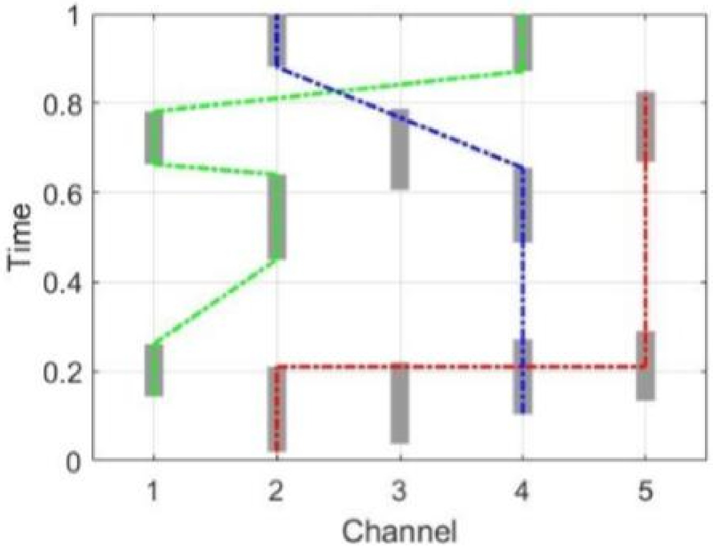
- 3 CRs, 5 Channels
- Periodic opportunities
- The discount factors λ_{Tm}, λ_c, λ_f and λ_n are set as 0.6, 0.6, 0.5 and 0.4.
- The threshold weight ε is 0.2.

	Channel 1	channel 2	channel 3	channel 4	channel 5
T_d	0.1181	0.1905	0.1823	0.1674	0.1568
Q	0.8883	0.5297	0.0087	0.4737	0.9537
P_c	0.0082	0.2320	0.2357	0.3324	0.7173
P_i	0.7473	0.5466	0.7483	0.7469	0.0297
P_f	0.1628	0.2710	0.2722	0.3250	0.1846

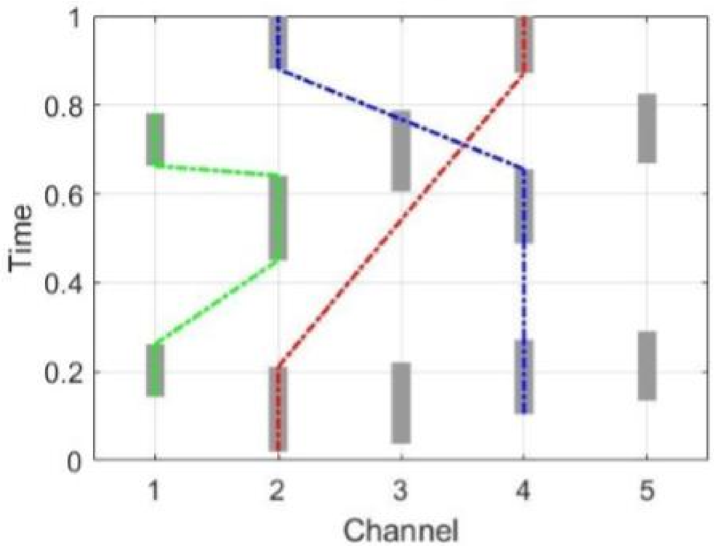
Experiment and Analysis

Demonstration Results

- Effecitiveness of QoS enabled handoff
- Different handoff scheme when discount value changes
- Effectiveness of the function of balancing loads



(a) $\lambda_c = 0.6$



(b) $\lambda_c = 0.5$

Experiment and Analysis

Conditions

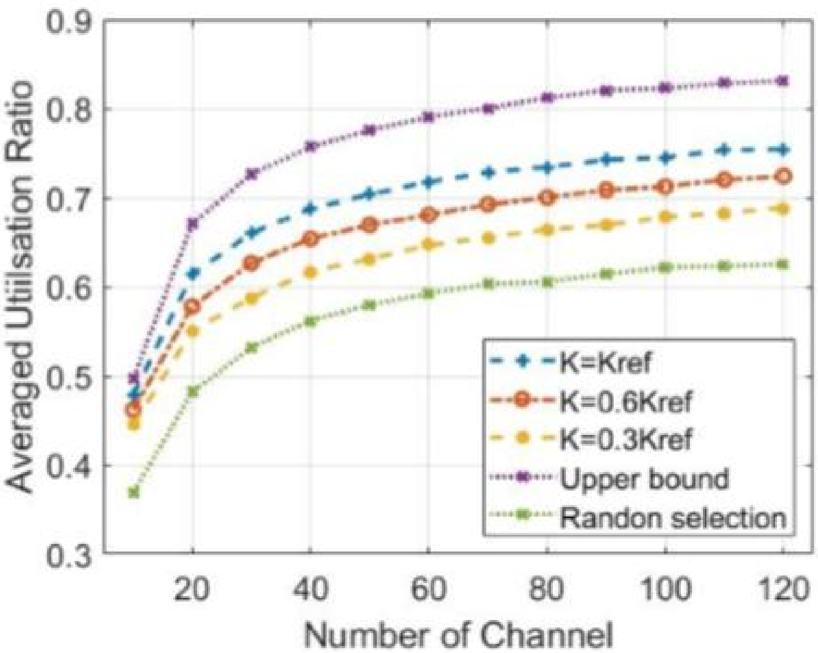
- Utilisation ratio

$$R = \left(\sum_{i=1}^{N} T_i\right) / (NT_s)$$

- Set reference point - $K_{ref} = \lambda_c + \lambda_f + \lambda_n$
- Random generation - Monto Carlo method
- Average utilisation ratio

$$\bar{R} = \left(\sum_{i=1}^{N_l} R_{N_l}\right) / N_l$$

- Upper bound - K=3



Results

- Greedy handoff scheme is more effecitive than random selection
- The ratio increases when channel number becomes larger, although the rate is decreasing.

Experiment and Analysis

Conditions

- Utilisation ratio
$$R = \left(\sum_{i=1}^{N} T_i\right) / (NT_s)$$
- Set reference point - $K_{ref} = \lambda_c + \lambda_f + \lambda_n$
- Random generation - Monto Carlo method
- Average utilisation ratio
$$\bar{R} = \left(\sum_{i=1}^{N_l} R_{N_l}\right) / N_l$$
- Lower bound - K=3

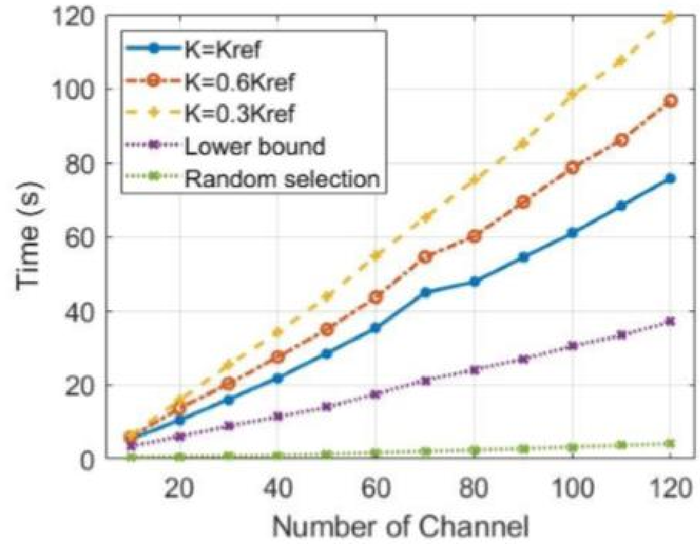


Fig. 5. Comparison of the time consumption vs number of channel N with different K

Results

- Greedy handoff scheme takes longer time than random selection
- Weaker constraints contribute to higher occupation of spectrum.

Conclusions

Contributions

Consider handoff issue as task allocation issue.
Propose greedy based solution.
Introduce QoS factors.

Conclusions

Spectrum utilization ratio can be improved by considering wider bandwidth (more channels) and making QoS requirements less strict. In both cases it leads to increase in time consumption for handoff scheme generation.

Future Work

Sensing based handoff. (learning based sensing.)
Hybrid handoff

Questions?