Problem Chosen	2021 MCM/ICM Summary Sheet	Team Control Number
B		**2112294**

Drone Firefighting Hero Saves Australian Forests

Summary

Bushfires in Australia are wildfires that frequently occur during the hot and dry season in Australia. A large area of land is destroyed every year, causing property damage and casualties. Wilderness fires are usually caused by lightning, or caused by human negligence and deliberate arson. Heat waves, droughts, and periodic cli- mate changes such as El Niño and the Indian Ocean Dipole can severely increase the fire crisis.

In order to control the fire in a timely and effective manner and avoid more serious loss of life and property, the government hopes that the Surveillance and Situational Awareness (SSA) drone will assist the Emergency Operations Center (EOC) to timely obtain the latest information and make the best choice. However, the transmission power of drone signal is affected by many factors such as distance and terrain. Therefore, it is the most effective solution to allocate drones reasonably according to the possibility of fire occurrence, severity, spread trend, etc., and get the maximum benefit at a small cost.

Therefore,we set up two models to help CFA purchase SSA drones, drones with repeater and arrange the drones with repeater into different topography and different size of fire.

For Drone Number Model(DNM), we divide the problem into two parts. One is to decide the number of SSA drones and the other is to decide the number of drones with repeater. To decide the the number of SSA drones, we find the optimized number to set SSA drones and applying greedy algorithm and Genetic Algorithm to find the optimized number of SSA drones. To decide the number of drones with repeater, we also firstly decide the number of place to set drones with repeater.

For Fading Model (FM), we divide it into three parts, firstly, consider how to communicate between two drones. Analyze angle and distance. Secondly, think about factors in the transmission. Thirdly, think about how the distance and angle influence transmission factors, find the function to describe them.

Keywords: Bushfire, Drone, Victoria, Relay Link Propagation Loss, Climate, FFDI

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1 Introduction

1.1 Background

Bushfires in Australia are wildfires that frequently occur during the hot and dry season in Australia. A large area of land is destroyed every year, causing property damage and casualties. Wilderness fires are usually caused by lightning, or caused by human negligence and deliberate arson. Heat waves, droughts, and periodic climate changes such as El Niño and the Indian Ocean Dipole can severely increase the fire crisis. Global climate change has exacerbated the climate phenomenon and made the summer hotter. In 2019, the continuous drought and high temperature, record-breaking high temperature and prolonged drought have contributed to bushfires, making the Australian bushfires in 2019-2020 more difficult to control.[9]

In order to control the fire in a timely and effective manner and avoid more serious loss of life and property, the government hopes that the Surveillance and Situational Awareness (SSA) drone will assist the Emergency Operations Center (EOC) to timely obtain the latest information and make the best choice. However, the transmission power of drone signal is affected by many factors such as distance and terrain. Therefore, it is the most effective solution to allocate drones reasonably according to the possibility of fire occurrence, severity, spread trend, etc., and get the maximum benefit at a small cost.

1.2 A Glance at the Data Sets

In order to come up with an informed and persuasive report, we have collected many data sets about Australia and especially Victoria, including key information on climate, fire conditions and topography. And the following three are the major data sets that we utilized to analyze,

- **Fires from Space: Australia, NASA Satellites Data MODISC6 and VIIRS 375m from 2019-08-01 to 2020-01-11 (FSA)**, a data set provided by NASA containing latitude, longitude and fire radiative power from 2019-08-01 to 2020-01-11 [1].
- **Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT)**, an integrated climate data set provided by the Australian Government including mainly the air temperature [6].
- **Digital Topographic Data (DTD)**, which is provided by the Australian Government and gives us detailed topographic data of Australia at different scales [10].
- **GEODATA 9 second DEM and D8: Digital Elevation Model Version 3 and Flow Direction Grid 2008(D8-9S)**, which describes the principal directions of surface drainage across the whole of Australia[11].

We decided to divide them into two categories, one for model building and the other for verifying the rationality of our model and its sensitivity to different data sources. In addition, we use the existing data and corresponding regional maps got from Google Map to fit the distribution of heat maps(e.g. shown as Figure 1), bushfire maps, so that readers can more intuitively understand the condition in Australia.

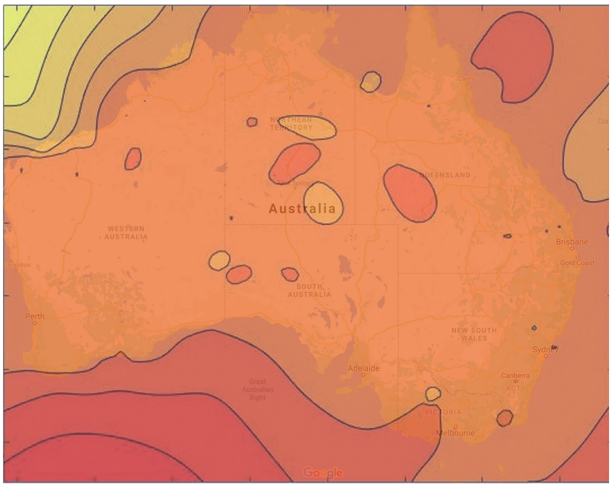
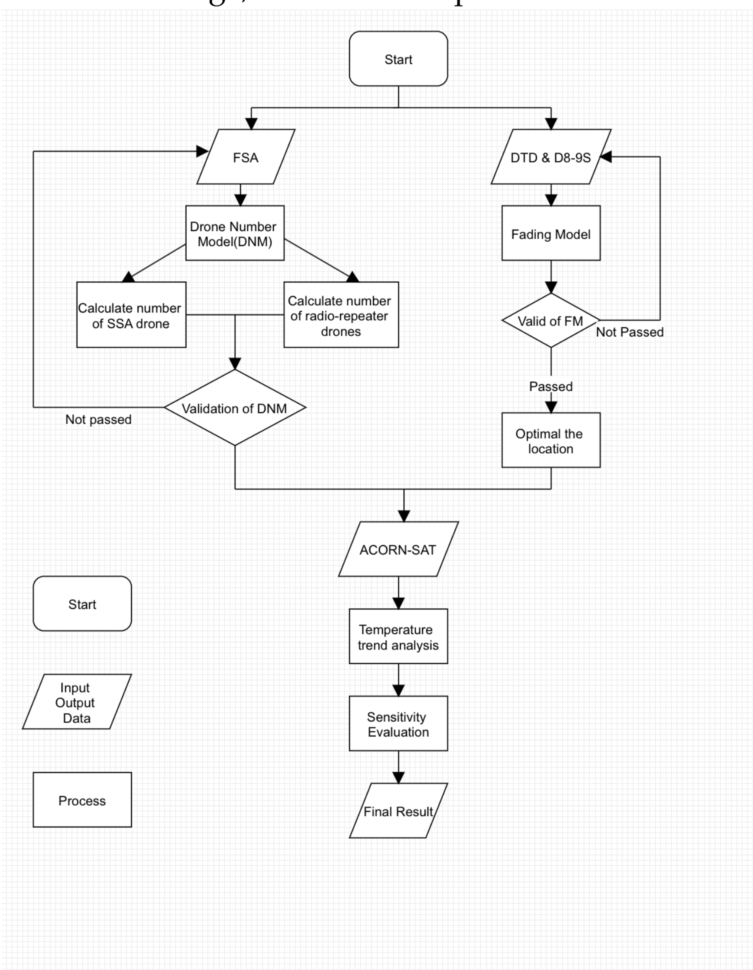


Figure 1. The Heat Map Combined with Topographic Map of Australia

2 Problem Analysis

In this problem, two kinds of drones are involved, one is SSA drones and the other is drones with repeater. So, we seperately find the optimized number of SSA drones and drones with repeater. And the range of drones with repeater will be greatly affected by topography, so we should set another model to find the how the range of drones with repeater will change, and find the optimized location for them.



3 Assumptions

- **Assumption 1: The fire propagates in the same speed in all direction.** We ignore the wind speed and due to recent research the fire will be a circle[7].
- **Assumption 2: The drones are stored and charged in the mobile EOC and the mobile EOC can drive to the edge of the fire.** Because according to the problem statement, A mobile EOC can be deployed near the site of an emergency.
- **Assumption 3: A place cannot catch on fire more than once a year** since ash cannot catch on fire.
- **Assumption 4: Normal fire lasts for one day and their size is almost the same because Normal fire is always put out within a day.**
- **Assumption 5: The antenna of radio-repeater transmit the same amount of power around it.** In order to maximize the communication range, the antenna of radio-repeater should be omnidirectional.
- **Assumption 6: Only temperature will change dramatically in ten years.** The greenhouse effect influenced the temperature first.
- **Assumption 7: City cannot be founded in mountain area.** According to the actual distribution of cities, it is unreasonable to set up a city in mountain area.
- **Assumption 8: The slopes of mountains are gently.** Since the real terrain is complex, we use this assumption to simplify the calculation.

4 Notations

Symbol	Definition	Unit
N_{SSA}	the number of place to set SSA drones	pcs
r_{SSA}	the range of SSA drones	Km
$N_{repeater}$	the number of place to set drones with repeaters	pcs
$r_{repeater}$	the range of drones with repeaters	Km
s	the size of fire	Km^2
r	the radius of fire	Km
f	the frequency of fire	$times$
n_{SSA}	the number of SSA drones	pcs
$n_{repeater}$	the number of drones with repeaters	pcs
$t_{charging}$	the time to charge WileE–15.2X Hybrid Drone	hr
t_{fly}	Maximum flight time of WileE–15.2X Hybrid Drone	hr
r_{drones}	Maximum flight range of WileE–15.2X Hybrid Drone	km
v	Maximum speed of WileE–15.2X Hybrid Drone	Km/hr
sum_{fire}	the total area of fire	km^2
sum_{times}	the total number of fire	$times$
n_{EOC}	the number of mobile EOC	pcs
m	the angle between mobile EOC and the closest place to set ASS drones	rad
ϕ	the azimuth angle	$\circ$
θ	the angle of pitch	$\circ$
$d_{repeater}$	the distance between two drones	m

(Continue in the next page)

Symbol	Definition	Unit
$r'_{repeater}$	the range of drones with repeaters in mountain area	Km
$p_{transmit}$	the power of signal transmission	w
L_f	the sum of path loss	-
L_R	the extra loss due to the rainfall	-

5 Drone Number Model (DNM)

5.1 Two Parts of DNM

To determine the optimal numbers and mix of SSA drones and Radio Repeater drones, we should divide DNM into two parts. One is to decide the optimal numbers of SSA drones and another to decide the optimal numbers of drones with repeaters.

5.2 The Number of SSA Drones

In assumption, we consider the fire region as a circle and fire fighters are on the edge of fire to put out the fire. And the WileE–15.2X Hybrid Drone can only fly r_{drones}. So for a given size s, the number of mobile EOC is:

$$n_{EOC} = \lceil \frac{s}{\pi r_{drones}^2} \rceil \tag{1}$$

Next, we are discussing about each EOC. Firefighters have 5-watt radios which has certain range. It means that the ASS drones should surround the fire and the range of drones is the range of SSA radio. And the range of SSA drones r_{SSA} will change because of topography.

To decide the number of place to set SSA drones, we make inscribed equilateral n-polygons in circle representing fire, $n \geq 3$. For $n < 3$, the situation is $\frac{s}{n_{EOC}} < \pi r_{SSA}^2$, n is always 1. For $n \geq 3$, which also means $\frac{s}{n_{EOC}} \geq \pi r_{SSA}^2$, the diameter of the circle of the ASS drones should larger than the length of the inscribed equilateral n-polygons in circle representing fire. the length of the inscribed equilateral n-polygons in circle representing fire can be calculated through law of cosines, and the number of sides is equal to N_{SSA}, so we get following:

$$\begin{cases} N_{SSA} = 1 & \frac{s}{n_{EOC}} < \pi r_{SSA}^2 \\ 4r_{SSA}^2 \geq 2r^2(1 - cos(\frac{2\pi}{N_{SSA}})) & \frac{s}{n_{EOC}} \geq \pi r_{SSA}^2 \end{cases} \tag{2}$$

Then, we will use the N_{SSA} to get n_{SSA}, the number of SSA drones. For a certain place to set SSA drones, the drone in this place take time to fly and charging,$t_{charging}$. During this time, other drones should be used to observe the fire. To get this time, we use geometry way to get the distance the drones fly. Combining with the v, Maximum speed of WileE–15.2X Hybrid Drone, the flying time is get. And the time that a drones can observe is Maximum flight time of WileE–15.2X Hybrid Drone, t_{flight} minus the flying time. Besides, we should consider how the place is arranged. θ is the angle between mobile EOC and the closest place to set ASS drones. And to simply, the θ is less than 2π divided by N_{ASS}. and the number of EOF n_{EOC}, frequency f should also be taken into account.

$$0 \leq m < \frac{2\pi}{N_{ASS}} \tag{3}$$

For the number of SSA drones, what finally optimized is as follow:

$$min. \quad n_{SSA} = n_{EOF} \cdot f \sum_{i=0}^{N_{ASS}-1} \lceil \frac{4rsin(\pi/N_{ASS} \cdot i + m)/v + t_{charging}}{t_{flight} - 4rsin(\pi/N_{ASS} \cdot i + m)/v} + 1 \rceil \tag{4}$$

5.3 The Number of Drones with Repeaters

For the range of drones with repeaters are always much larger than the range of SSA drones. And if the the area of fire for a certain EOC $\frac{s}{n_{EOC}} < \pi r_{SSA}^2$ is smaller than the $r_S SA$ and no drones with repeater will be used. So the place equation is as follow:

$$\begin{cases} N_{repeater} = 0 & \dfrac{s}{n_{EOC}} < \pi r_{SSA}^2 \\ N_{repeater} = 1 & \dfrac{s}{n_{EOC}} \geq \pi r_{SSA}^2 \end{cases} \tag{5}$$

Then we are going to decide the number of drones with repeaters, $n_{repeater}$. There are only two cases, so we directly find the optimized way using geometry way and the condition mentioned in the part of The number of drones with repeaters.

$$\begin{cases} n_{repeater} = 0 & \dfrac{s}{n_{EOC}} < \pi r_{SSA}^2 \\ n_{repeater} = n_{EOF} \cdot f \cdot \lceil \dfrac{2 \cdot (2r - r_{repeater})/v + t_{charging}}{t_{fly} - 2 \cdot (2r - r_{repeater})/v} + 1 \rceil & \dfrac{s}{n_{EOC}} \geq \pi r_{SSA}^2 \end{cases} \tag{6}$$

5.4 Combination of the Two Parts

Combine these two parts, the DNM becomes a nonlinear programming.

$$min. \quad n_{SSA} + n_{repeater} \tag{7}$$

And s.t. are all the equations in the parts of second and third part of Drone Number Model(DNM). And greedy algorithm can be applied to find the optimized number. Firstly, find the optimized $N_S SA$ for the equation:

$$2r^2(1 - cos(\frac{2\pi}{N_{SSA}})) \tag{8}$$

is decreasing as N_{SSA} increases, and N_{SSA} is nature number. So we can use numeration method to find the optimized N_{ASS}. Secondly, based on the N_{SSA} we find, We can use GA to find the final optimal $n_{SSA} + n_{repeater}$.

5.5 Application of DNM in Victoria

From the website of CFA[3], we find that the CFA divides the Victoria state into 20 districts. And to consider the topography, we combine the graph in the question with the graph from CFA[3].

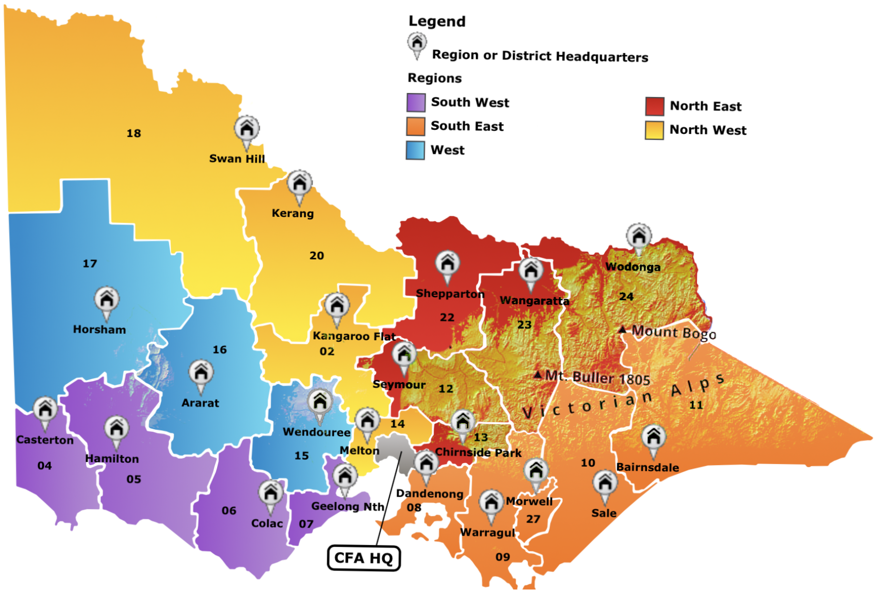


Figure 2. CFA's districts of Victoria [1]

We will apply the DNM to each district and find the optimized n_{SSA} and $n_{repeater}$. To find the size and frequency, data set FSA is used.

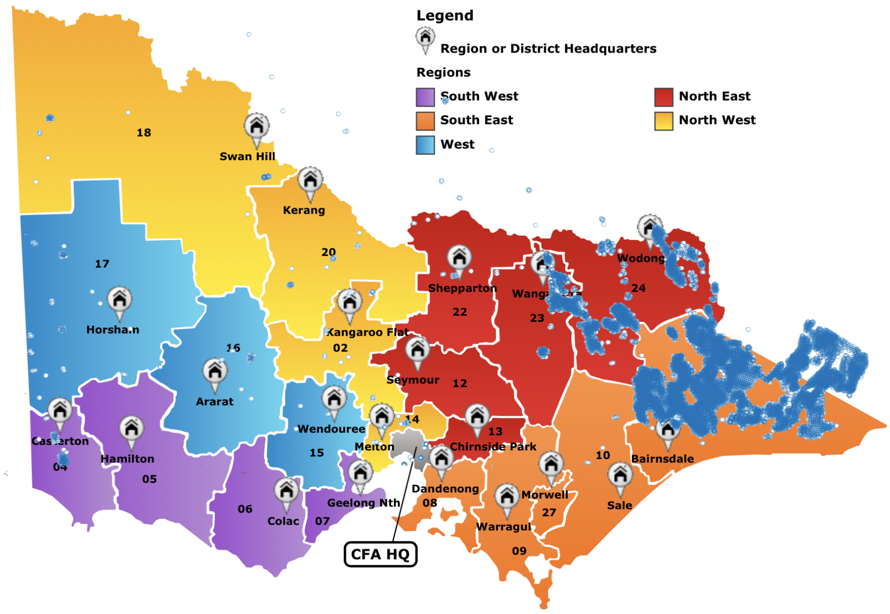


Figure 3. distribution of fire based on FSA

[1] Background screen shot from the website of CFA and and the topography is from MCM 2021 B.

From the graph, it demonstrates that the fire in district 23, 24 and 11 is severe fire and the remaining district is in normal fire. And from the victorian government's website[2], we get the total area of fire in Victoria is 15026.74 km^2. The data set FSA also demonstrates that there is 13410 times fire and 1928 times normal fire. Based on this data, frequency f and size s can be calculated. And $t_{charging}$ is 1.75 hr. Maximum speed of WileE–15.2X Hybrid Drone, v is 72 km/hr. Maximum flight range of WileE–15.2X Hybrid Drone, r_{drones} is 30 km. Maximum flight time of WileE–15.2X Hybrid Drone,t_{fly} is 2.50 hr. Based on this data, following outcome is found.

district	n_{SSA}/pcs	$n_{repeater}$/pcs
02	4	0
04	4	0
05	4	0
06	4	0
07	4	0
08	4	0
09	4	0
10	4	0
11	1625	26
12	4	0
13	4	0
14	4	0
15	4	0
16	4	0
17	4	0
18	4	0
20	4	0
22	4	0
23	312	6
24	635	14
SUM	2640	46

Table 1: The optimized n_{SSA} and $n_{repeater}$

So the mix of SSA drones and drones with repeater is $\frac{n_{SSA}}{n_{repeater}} = \frac{57}{1}$. And n_{SSA} is 2640 pcs, $n_{repeater}$ is 46 pcs. Totally, 2686 pcs drones are needed and price is \$ 26,860,000 (AUD).

6 Fading Model (FM)

6.1 The Fundamental Principle of Communication of Hovering VHF/UHF radio-repeater drones

After setting up the DNN model, we preliminarily determine the number of drones in Victoria Area. However, in the east of region of Victoria, the terrain is very complex, such as the highest mountain, Mt. Bogong has an attitude of 1986 meters. Mountainous and high-altitude environment force us to consider the probable signal fading in the procedure of communication between drones.

Although a great number of drones formed a radio-repeater networks, only one drone can each drone interact with at the same time. Therefore, we just need to determine how the communication channel be founded between two radio-repeaters. Inspired by the study of Hu Xujun's team, *Propagation Loss and Performance Evaluation of UAV Relay Link*[8], we developed our own radio-repeater communication system as Figure shows. The rounds of communication range are circumscribed to keep the minimize the cost as well as maximize the cover area. The $r_{repeater}$ represents the range of drones carrying repeaters can reach on the open ground. The $d_{repeater}$ represents the distance between two drones divided by two.

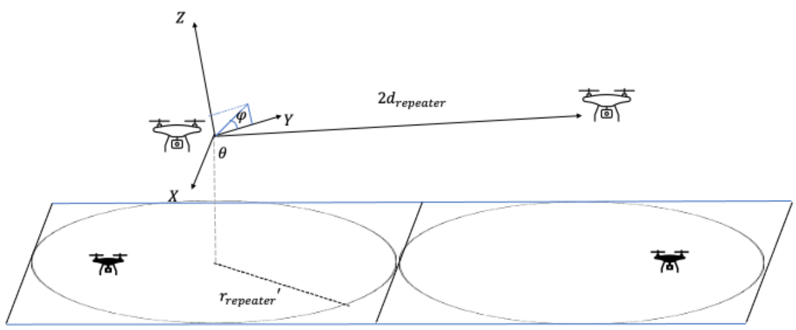


Figure 4. Double Radio-Repeater Communication System

Then, we set up a Cartesian coordinate system at the origin of one of the drones. Denote the location of another drone with a coordinate (x,y,z), the azimuth angle of $2d_{repeater}$ with ϕ, the angle of pitch with θ. Then we can draw these equations:

$$\phi = arcsin(\frac{z}{\sqrt{z^2 + y^2}}) \tag{9}$$

$$\theta = arccos(\frac{x}{|2d_{repeater}|}) = arccos(\frac{x}{\sqrt{x^2 + y^2 + z^2}}) \tag{10}$$

$$d_{repeater} = \frac{r_{repeater}\prime}{cos\theta} \tag{11}$$

6.2 The Analysis of Relay Link Propagation Loss

Referring to the study, Propagation Loss and Performance Evaluation of UAV Relay Link[8], for any two adjacent drone nodes in the network, we should comprehensively consider the Antenna gain, propagation loss and climatic factors. Then we can obtain:

$$P_{transmit} = P_{EOC} L_f L_R \times \prod G_{repeater} \times \prod \alpha \tag{12}$$

Among them, $P_{transmitte}$ represents the power of signal transmission, P_{EOC} represents the transmission power of EOC. $G_{repeater}$ represents the gain of repeaters which depends on the angle of signals. L_f represents the sum of path loss, L_R represents of the extra loss due to rainfall. α represents the random fading caused by large scale fading and small scale fading.[8]

In our model, comprehensively analyzing various geographical factors, we draw the conclusion that $P_{EOC} L_R$ are probabilistically constant. The only factors we need to consider are the gain of each repeaters $G_{repeater}$, path loss $L_f$and random fading factor α.

Referring to Propagation Loss and Performance Evaluation of UAV Relay Link[8], we the obtain the equation of path loss:

$$L_R = \left(\frac{4\pi f}{c} \cdot 2d_{repeater}\right)^2 \tag{13}$$

And for convenience, we can denote the $G_{repeater}$ as following equation:

$$G_{repeater} = \eta \cdot \frac{4\pi}{\int_0^{2\pi} \int_0^{\pi} F(\theta, \phi) sin\theta d\theta d\phi} \tag{14}$$

In this equation, $F(\theta, \varphi)$ is a normalization function, which reflects field intensity distribution in different directions. η represents the efficiency of the antenna. φ represents the azimuth angle and θ represents the angle of pitch. While in our assumption the antenna of radio-repeater is omnidirectional, we can denote the normalization function as:

$$F(\theta, \varphi) = cos^2(k\theta) + c \tag{15}$$

Then we obtain this equation:

$$G_{repeater} = \eta * \frac{4\pi}{\int_0^{2\pi} \int_0^{\pi} \left[cos^2(k\theta) + b\right] sin\theta d\theta d\phi} \tag{16}$$

$$L_R = \left(2\frac{4\pi f}{c} \cdot \frac{r_{repeater}}{cos\theta}\right)^2 \tag{17}$$

Combining equation (16) and (17), for two radio-repeaters, we have

$$P_{transmitte} = P_{EOC} \cdot \left(2\frac{4\pi f}{c} \cdot \frac{r_{repeater}}{cos\theta}\right)^2 \cdot (\eta * \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi}\left[cos^2\left(k\theta\right)+b\right]sin\theta d\theta d\phi})^2 \quad (18)$$

6.3 Locations to hover VHF/UHF radio-repeater drones

For the $r_repeater\prime$ is not always much larger than the range of SSA drones, r_{SSA}. so the place to set the drones with repeater will be like the way that decides the number of place to set SSA drones. And all other parameters will be the same. The equation is as follow:

$$\begin{cases} N_{repeater} = 1 & \frac{s}{n_{EOC}} < \pi r_{SSA}^2 \\ 4r_{repeater}^2 \geq 2r^2(1 - cos(\frac{2\pi}{N_{SSA}})) & \frac{s}{n_{EOC}} \geq \pi r_{SSA}^2 \end{cases} \quad (19)$$

For a given size, the r is constant, and $N_{repeater}$ is natural number. So graph of this equation is as follow:

$$2r^2(1 - cos(\frac{2\pi}{N_{repeater}})) \quad (20)$$

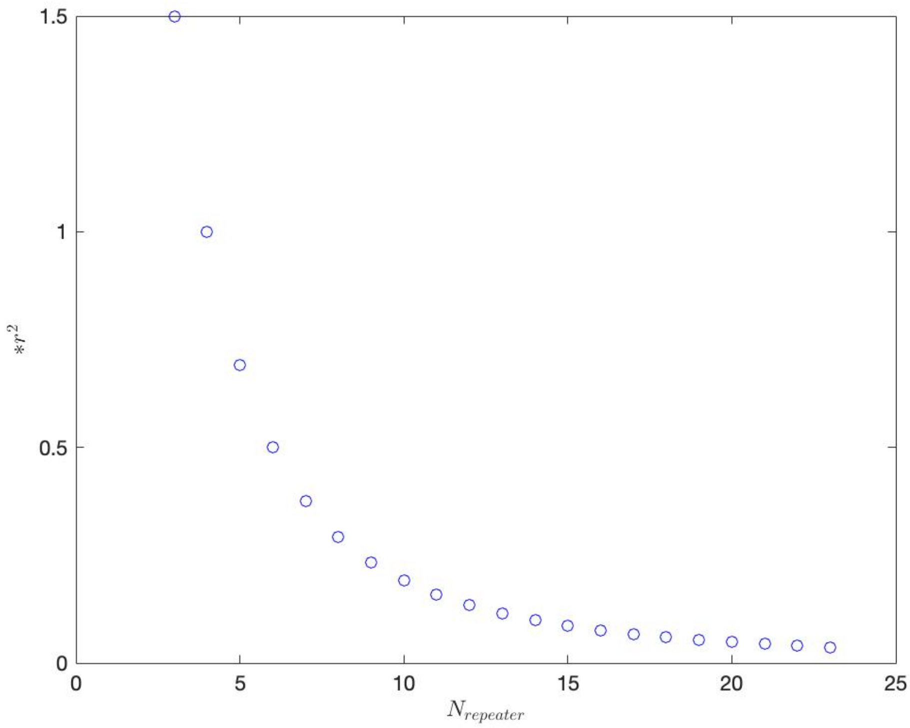


Figure 5. The Figure of the equation $2r^2(1 - cos(\frac{2\pi}{N_{repeater}}))$

From this picture, it shows that the equation decreases as $N_{repeater}$ increases. And we can use enumerate method to find the optimized $N_{repeater}$. The optimized way to locate the drones with repeater.

The figure to show how to set the drones with repeater when $N_{repeater}$=6 is as following, Blue circle is the fire, and the center of red circle is the drones with repeater.

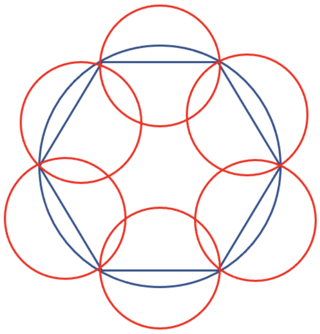


Figure 6. The location of drones with repeater

7 Sensitivity Evaluation

7.1 The climate change in Victoria

While there are many factors can influence the frequencies of bushfires, including terrains, vegetation and climate, the factors most likely to change dramatically on a time scale is climate caused by the greenhouse effect. Therefore, the main factor we interested in is the climate variation.

One of the most important indexes to reflect the change of climate is the change of temperature. According to Australian Bureau of Meteorology, Figure 7 shows the change of average temperature of Australia:

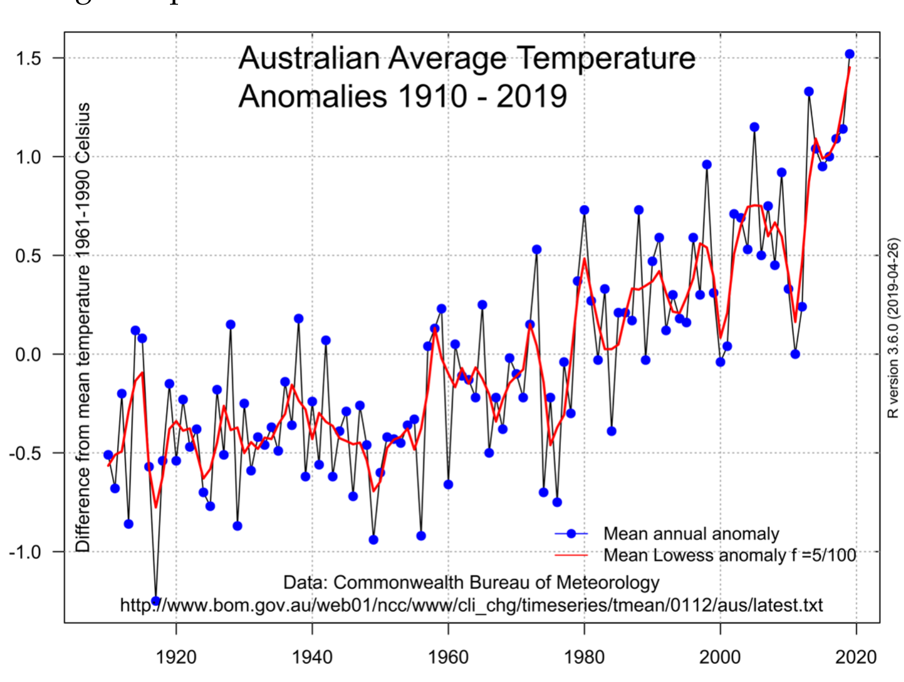


Figure 7. Australian Average Temperature Anomalies

Source: This figure is cited from Wikipedia `https://en.wikipedia.org/wiki/Climate_change_in_Australia` and its data comes from `http://www.bom.gov.au/web01/ncc/www/cli_chg/timeseries/tmean/0112/aus/latest/txt`

And in order to further study the climate change in Victoria, and avoid the interference of contingency, we treat a decade as a unit, record the 10th extreme temperature in Victoria past fifty years. (The highest records are always highly contingent, thus we use the 10th extreme temperature[6].)

Temperature(°C)	Date	Station Name(Number)	Evelation(m)	Latitude(°)	Longitude(°)
45.4	31-Jan-20	Swan Hill Aerodrome(77094)	71	-35.38	143.54
44.5	11-Jan-10	Hopetoun Airport(77010)	77	-35.72	142.36
43.0	3-Feb-00	Bairnsdale Airport(85279)	49	-37.88	147.57
43.7	3-Jan-90	Lemnos(Campbells Soup)(81084)	113	-36.36	145.46
43.4	20-Feb-80	Walpeup Research(76064)	105	-35.12	142
42.8	9-Feb-70	Ouyen(Post Office)(76047)	50	-35.07	142.32
41.2	17-Jan-60	Wodonga Express(82056)	152	-36.12	146.9

Table 2: Extreme Temperature Records in Victoria

Source: Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT), an integrated climate data set provided by the Australian Government including mainly the air temperature [6].

Then we use computer to fit the trend of change of extreme temperature appearing in Victoria. From this picture we can find the temperature linearly increasing over years, about 0.2 degrees Celsius per year. And the predicted extreme temperature of 2030 is about 45.62°C.

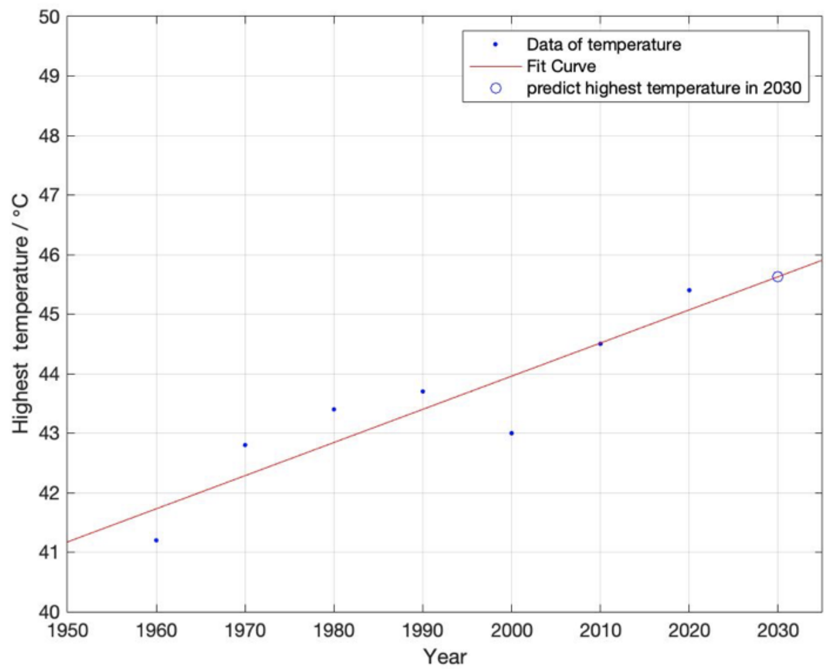


Figure 8. The rising of the highest temperature

7.2 The Temperature Influence of Bushfire Risk

In order to quantify the risk of bushfire, in 1960s, CSIRO scientist A. G. McArthur developed an equation named FFDI to calculate. The definition of FFDI is given following:

$$FFDI = 2e^{-0.45+0.987\ln(DF)+0.0338T-0.345RH+0.0234U} \tag{21}$$

Among this, DF represents draught factor, T represents temperature, RH represents wind speed and U represents humidity. Then, to study how the single variable, temperature impacts on the FFDI, we can simplify this equation to:

$$FFDI' = 2exp(0.0338T + k) \tag{22}$$

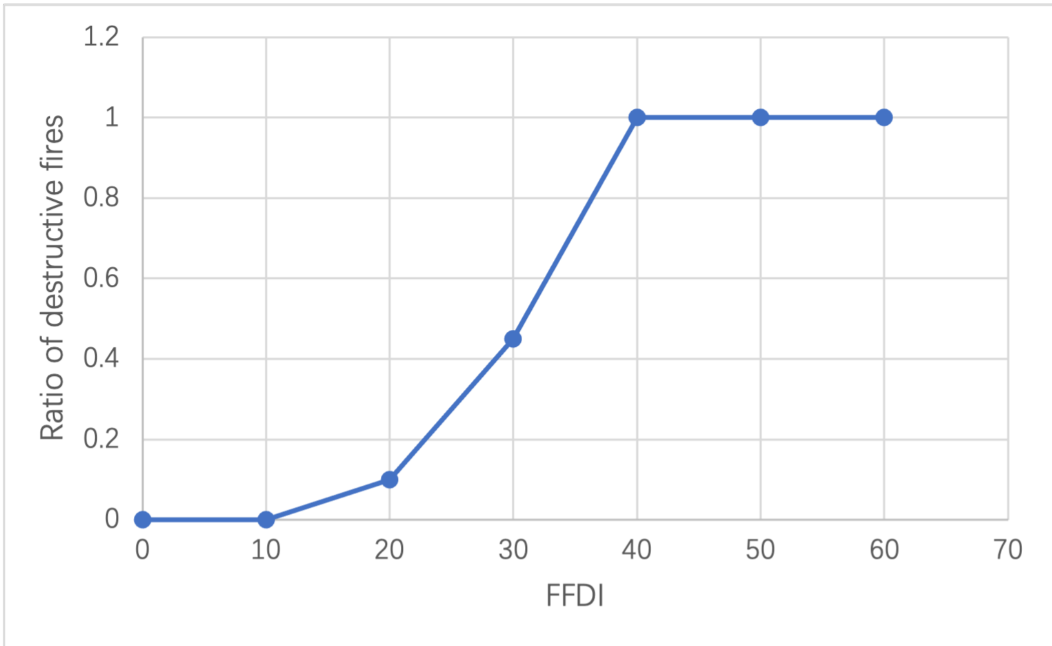


Figure 9. The variation of Ratio of destructive fires

Source: This Figure based on data from Climate change impacts on fire-weather in south-east Australia

And using the data comes from Climate change impacts on fire-weather in south-east Australia. We obtain the relationship between the ratio of destructive fires and FFDI. And when we want to study the extreme fire, for a constant fire danger index, we can assume that fire frequency and fire size are inversely proportional. Since FFDI is proportional with their product, and we will obtain:

$$FFDI' = s \cdot f \tag{23}$$

Here s represents the size of fire and f represents the frequencies of drones. Then we can use the extreme temperature to calculate the highest FFDI in a year.

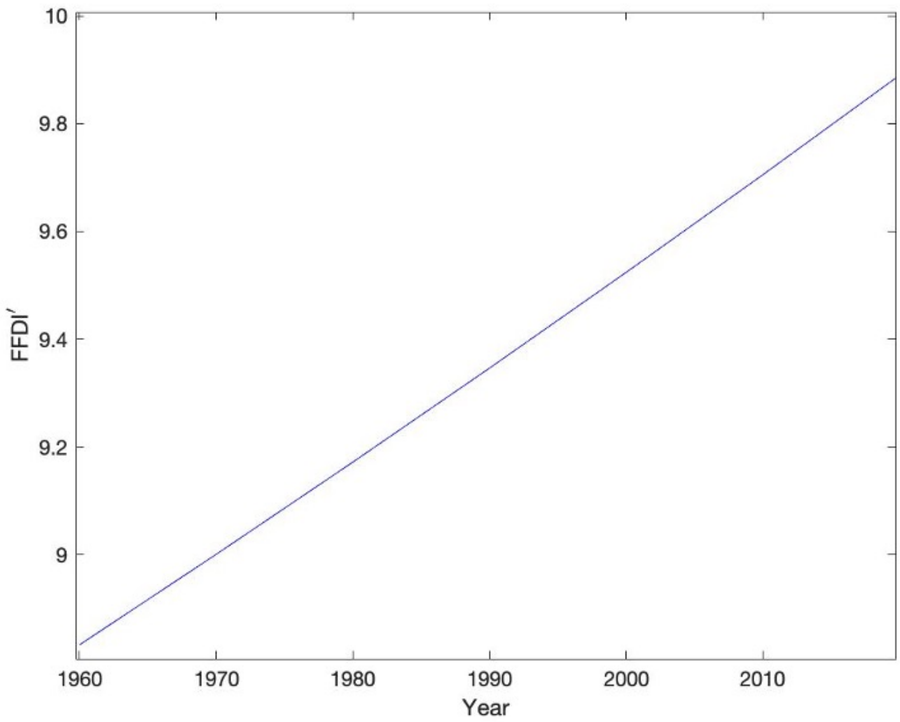


Figure 10. The variation of FFDI over years

7.3 Model Sensitivity Evaluation of DNM

The sensitivity evaluation of DNM is using the higher temperature in future years. In order to test adaptivity of our model DNM, firstly we calculate the $FFDI'$ in 2030, and we will get : $FFDI' = 10.077$

Considering the extremely destructive bushfires have similar frequency. Thus, we keep the f constant to determine the size of fire in 2030. $s' = 1.0077s$

Retrieve this size of fire to DNM, considering the extreme fires always appear in district 11, it is reasonable to only consider the extreme fires in district 11, then calculate the necessary numbers of drones.

Plug in, we find we need 1636 SSA drones and 26 drones with repeater. And compared with 2020, 11 more SSA drones are needed. Thus, the cost of SSA increase 11000 (AUD), which are within the range of our expectations.

7.4 Model Sensitivity Evaluation of FM

The FM model only includes gain of radio-repeaters, the transmission power of EOC and the path loss. When ignoring the influence of random fading, it cannot properly adapt to the mountain with excessive inclination or very complex terrain. However, after assessing the terrain in Victoria, and with the condition that EOC is mobile which can appear immediately. These problem can be ignored and it can adapt to the situation of bushfire in Victoria.

8 Strengths and Weaknesses

8.1 Strengths

- **The number and mix of drones calculated by our model are very stable, it can also deal with the extreme fire in the future.** Because our model is based on a large data set and it contains ,any parameters, so it has a great stability.
- **The model is easy to apply.** Because our model is not only based on mathematics and algorithm, but also take social element into account. For example, our model is based on the district divided by CFA.

8.2 Weaknesses

- **Our model assumes the fire as a circle**, but in the real world, there exists wind speed and different underlying surface. This will cause the fire not to be a perfect circle.
- **Our model cannot deal with steep topography**, because in model FM, to simply, to ignore some parameters. And these parameters will affect our model when the topography is steep.

9 Conclusion

To sum up, we set up two models to help CFA purchase SSA drones, drones with repeater and arrange the drones with repeater into different topography and different size of fire.

- For Drone Number Model(DNM), we divide the problem into two parts. One is to decide the number of SSA drones and the other is to decide the number of drones with repeater. To decide the the number of SSA drones, we find the optimized number to set SSA drones and applying greedy algorithm and Genetic Algorithm to find the optimized number of SSA drones. To decide the number of drones with repeater, we also firstly decide the number of place to set drones with repeater.
- For Fading Model (FM), we divide it into three parts, firstly, consider how to communicate between two drones. Analyze angle and distance. Secondly, think about factors in the transmission. Thirdly, think about how the distance and angle influence transmission factors, find the function to describe them.

Due to the DNM, it shows that the mix of SSA drones and drones with repeater is $\frac{n_{SSA}}{n_{repeater}} = \frac{57}{1}$. And n_{SSA} is 2640 pcs, $n_{repeater}$ is 46 pcs. Totally, 2686 pcs drones are needed and price is \$ 26,860,000 (AUD). And for FM, it can successfully arrange the location of drones with repeater in different topography .

10 Annotated Budget Request for Country Fire Authority (CFA) to the Victoria State Government

Dear *Victoria State Government*,

We are very pleased to hear that you are willing to use drones to help solve the bushfire problem which has an intensified trend in recent years and has caused serious loss of life and property to Australia. Besides, We are also honored to have the opportunity to share our reasonable budget obtained by database analysis, with which we hope we can make contributions to protecting species diversity and minimizing losses.

Bushfires in Australia are frequent wildfires that occur during Australia's hot and dry seasons. Heat waves, droughts and cyclical climate change can seriously increase the fire crisis, while global climate change exacerbates climate phenomena that make summers hotter. Persistent drought and heat, record-breaking heat contributed to bushfires in 2019, making the 2019-2020 Australian bushfires more difficult to control. If we fail to prevent this from happening, Australia's ecology and economy will be seriously threatened and the lives of a large number of people will be affected. In this case, timely and effective monitoring, to avoid more serious loss is particularly important. Surveillance and situational awareness (SSA) drones assist the Emergency Operations Center (EOC) to obtain the latest information in a timely manner to make the best choices. However, the transmission power of drone signals is affected by many factors such as distance and terrain.

We use data to analyze the possibility, severity, and spreading trends of fires, and build models to comprehensively consider the impact of terrain factors on drone signal transmission to allocate drones. We found that areas with severe fires need more SSA drones to respond quickly, and areas with large areas of fire and large undulating terrain required more drones with repeaters. We got the results shown in the following list.

district	n_{SSA}/pcs	$n_{repeater}$/pcs
Kangaroo Flat	4	0
Casterton	4	0
Hamilton	4	0
Colac	4	0
Geelong Nth	4	0
Dandenong	4	0
Warragul	4	0
Sale	4	0
Bairnsdale	1625	26
Seymour	4	0
Chirnside Park	4	0
Melton	4	0
Wendouree	4	0

(continue in the next page)

district	n_{SSA}/pcs	$n_{repeater}$/pcs
Ararat	4	0
Horsham	4	0
Swan Hill	4	0
Kerang	4	0
Shepparton	4	0
Wangaratta	312	6
Wodonga	635	14
SUM	2640	46

Table 3: The optimized n_{SSA} and $n_{repeater}$

From it, we can easily see that SSA drones and drones with repeaters are mainly distributed in the northeastern part of Victoria, including Bairnsdale, Wangaratta and Wodonga, where the fire is more serious and the scope is wider, and the terrain is more undulating. And totally, we need 2640 SSA drones and 46 drones with repeaters, with 26.86 million Australian dollars.

We wish that our efforts will help the Victorian Government monitor bush fires in a timely manner and take the necessary action to prevent potential damage. We also hope all lives can live in a better ecological environment.

Yours sincerely,

Team #2112294

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